LAUER

The Effect of the Disposition
of bent up Bars upon the
Web Resistance of
Reinforced Concrete Beams

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THE EFFECT OF THE DISPOSITION OF BENT UP BARS UPON THE WEB RESISTANCE OF REINFORCED CONCRETE BEAMS

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BY

WILLARD WOOD LAUER

B. S. Carnegie Institute of Technology, 1916

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN THEORETICAL AND APPLIED MECHANICS

IN

THE GRADUATE SCHOOL

OF THE

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June 2, 1917

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY WILLARD WOOD LAUER

ENTITLED THE EFFECT OF THE DISPOSITION OF BENT UP BARS UPON THE WEB RESISTANCE OF REINFORCED CONCRETE BEAMS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN THEORETICAL AND APPLIED MECHANICS.

A N Talbot
In Charge of Thesis

A N Talbot
Head of Department

Recommendation concurred in:*

....	Committee
....	on
....	Final Examination*

*Required for doctor's degree but not for master's.

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THE EFFECT OF THE DISPOSITION OF BENT UP BARS UPON THE WEB RESISTANCE OF REINFORCED CONCRETE BEAMS.

I. INTRODUCTION

1. Preliminary: Numerous tests have been made previous to those undertaken in this series to determine the effectiveness of bent up reinforcing bars in resisting web stresses in reinforced concrete beams. The tests by Prof. C. Bach of Stuttgart, on beams with bars bent up and hooked, throw considerable light upon the effect of such web reinforcement upon the shearing strength of the beams. None of the former tests, however, were conducted in such a manner as to indicate definitely the distribution of the stress among and along the inclined bars. With the purpose of obtaining information on the distribution of stresses, and on the effect of different dispositions of bent up reinforcing bars upon the web strength of reinforced concrete beams the tests herein described were undertaken.

2. Scope: Beams were built in duplicate according to twenty different designs, making forty beams in all. Owing to the lack of time, however, it was found possible to test only twenty five beams of the series; this included one of each kind and duplicates of five of these beams.

The tests were intended to furnish information on; (1) The effect of varying the amount of steel bent up; (2) The effect of bending up the same amount of steel at different points; (3) The effect of varying the angle of bend, and (4); The distribution of the stress in the steel both along the length of the bars and among the

bars bent up at different places.

It is believed that the results of these tests will furnish some additional information on the effect of bent up bars upon the web resistance of reinforced concrete beams.

3. Formulas: For determining the proper radius of curvature of bends in the bars at point of bending up the following formula was used.

$$\frac{R}{d} = \frac{f_s}{4\ f_c}$$

$$\text{or}\quad \frac{R}{d} = \frac{.7854\ f_s}{f_c} \qquad (1)$$

where f_s = unit-stress in steel at yield point.

and f_c = unit-stress in concrete in bearing against reinforcing bar at yield point of steel.

R = radius of bend of bar.

d = diameter of bar.

For the largest sized bar used d was one inch. Using 40000 lb. per sq. in. for the stress in steel at yield-point and 4000 lb. per sq. in. in the concrete at the same time.

$$R = 7.85 \text{ inches.}$$

The radius of bend at the bottom bends was made 7 inches for all bars. The radius of the bends at the top of the beam and in the hooks at the ends was cut down to 3 inches. It was believed that the bars at these latter points would not receive a tensile stress near their ultimate strength. This was borne out by the test results which show that at the top of the beam the bars took compression at the earlier stages of loading and only at loads near the maximum did any tension get into them. Consequently at the upper point of bends, and at the ends, where the stress is low in the steel the tendency

for the concrete to crush out under the bends is considerably less than at the points of bending up from the bottom.

In figuring the tensile stress in the steel at maximum loads tabulated in the summary of tests the following formula was used.

$$f_s = \frac{M}{Ajd}$$

Where M is the bending moment in inch-pounds.

A is the area of steel.

jd is the arm of resisting couple.

d is the depth to center of steel, and

f_s is the unit-stress in the steel.

The shearing stress at the maximum load was computed by the formula $v = \frac{V}{bjd}$

Where b is breadth of beam.

v is shearing unit-stress.

V is total shear.

Computation of the compressive stresses using various values of q, (ratio of unit-deformation at load considered, to ultimate unit-deformation) and values of n indicated by the tests of the control cylinders show that q must lie somewhere between 0.7 and 1.0 and that n must lie between about 8 and 12.

Computations for Beam 16-B4-1. At the maximum load of 41600 pounds gave the following extreme range of possible stresses.

n	q	f_s	f_c
8	0.7	41100	4630
10	0.8	42200	4220
12	1.0	43800	3690

It is apparent that any computation which may be made will give a stress in the concrete close to 4000 lb. per sq.in. Since no failures were primarily by compression and because of the uncertainty as to the proper constants the computed concrete stresses have not been included in the summary of results. For the computations of steel stress n was taken as 10 and q as 0.8.

With the exception of the beams of group 16-B2, the area of the steel used in the beams was close to three square inches, which gives a value of p (ratio of reinforcement) of .0375. With the values of p, given in the table, (n equal to 10 and q as 0.8) values for j and K were computed and for use in figuring the stresses, interpolations were made to correspond to the "p" for various cases.

TABLE I.

COMPUTED VALUES OF k AND j.

Value of p	Value of k	Value of j
.0375	.618	.775
.0322	.594	.784
.0275	.569	.793

For this table n = 10 and q = 0.8

The values of k were obtained by the use of the following formula from Bulletin 4 University of Illinois Experiment Station.

$$k = \sqrt{\frac{2pn}{1-\frac{1}{3}q} + \frac{(pn)^2}{(1-\frac{1}{3}q)^2}} - \frac{pn}{1-\frac{1}{3}q}$$

For j the following formula was used, $j = 1 - \frac{1-.25q}{3-q}k$

4. Acknowledgement: These tests were a part of a series carried out in the University of Illinois Experiment Station. They were planned and carried out under the direction of Prof. A. N. Talbot. The test specimens were made under the supervision of Mr. H. F. Gonnerman of the Experiment Station by men experienced in reinforced concrete work. Prof. W. A. Slater, of the Experiment Station was in direct charge of the tests, and to him and Mr. Gonnerman credit is due for helpful suggestions and criticisms during the progress of the work. Mr. B. Pepinsky, and Mr. W. L. Parish rendered efficient assistance in making the tests. Acknowledgement is here made to these gentlemen for their assistance and advice.

II. MATERIALS, TEST SPECIMENS, AND METHODS OF TESTING.

5. Concrete Materials: The materials used for the concrete were obtained in the open market.

Cement: For the beams and auxiliary specimens Universal Portland Cement was used. Table II on the following page shows the results of the briquette tests of the cement. The tests include briquette made with a 1:3 mortar of Standard sand, and also with a 1:3 mortar of the Attica sand, which was used in the beams. The results indicate that a good quality of cement was used.

Sand: The sand used was a torpedo sand, obtained in the open market from near Attica, Indiana. It was fairly clean and well graded. The results of the sieve analysis are shown in Table III.

Gravel: Washed gravel obtained from Attica, Indiana was used. It was clean and well graded, passing thru a one inch mesh and being retained on a $\frac{1}{4}$-in. mesh. The sieve analysis is given in Table IV.

TABLE II.

BRIQUETTE TESTS OF CEMENT.

Tensile Strength in Pounds per Square Inch At Age of,

	7 days			28 days		
Sample	Neat.	1:3 mortar		Neat.	1:3 mortar	
Number		Standard sand	Attica sand		Standard sand	Attica sand
1	560					
2	644			793		
3	592	242	326	636*	355	476
4	630	223	379	735	272	537
5	654	234	271*	780	317	431
6		233	343		317	463
7		230	332		329	416
Average	613	232	345	769	318	465

Notes:

* Poor test not included in the average.

Each value in the above table is the average of five tests.

TABLE III.

SIEVE ANALYSIS OF SAND.

Sample Number	Percent Passing Sieve Number.							
	3 (.263)	4 (.185)	8 (.093)	14 (.046)	28 (.0232)	48 (.0116)	100 (.0058)	Pan
1	99.5	97.0	73.7	42.2	17.5	6.8	2.7	0
2	99.4	96.4	76.1	48.2	22.0	9.2	4.0	0
3	99.6	97.1	76.5	47.5	22.3	10.5	5.0	0
4	98.8	96.8	75.2	45.7	19.8	8.0	3.8	0
5.	95.7	93.3	71.6	43.3	18.7	6.1	0.2	0
6	99.2	90.7	53.4	29.4	10.6	4.8	1.8	0
7	97.9	94.2	67.7	37.7	14.2	4.4	1.1	0
8	98.0	95.1	71.5	40.7	16.7	6.2	1.8	0
9	98.1	95.2	73.0	44.0	18.7	7.5	3.1	0
10	99.5	97.1	75.0	44.3	19.3	7.9	2.4	0
Average	98.6	95.3	71.4	42.3	18.0	7.1	2.6	0

The sieve openings are of the sizes given in parenthesis under the sieve number.

TABLE IV

SIEVE ANALYSIS OF GRAVEL

Values are the Average of Five Tests.

Sample Number	Weight of Sample grams	Percent Passing Screens of Sizes Given.						
		1-in.	$\frac{3}{4}$-in.	$\frac{1}{2}$-in.	$\frac{3}{8}$-in.	.263-in.	.185-in.	Pan
1	3000 g.	100.0	79.8	43.6	17.8	5.3	1.5	0
2	3000 g.	99.1	71.6	39.2	14.0	3.2	0.2	0
3	3000 g.	97.7	71.5	35.3	16.1	6.1	1.4	0
4	3000 g.	100.0	70.5	37.6	11.7	3.3	0.7	0
5	2000 g.	100.0	71.3	30.3	11.3		0.4	0
Average		99.4	72.9	37.2	14.2	4.5	0.84	0

6. Specimens: The beams were all 8 in. wide and had a total depth of 12 in. The length over all was 10 ft. In all cases the reinforcement was placed in two layers. The center of the upper layer was 9 $\frac{1}{4}$ in. below the top of the beam and the center of the lower layer was 10 $\frac{3}{4}$ in. below the top of the beam. Thus the depth to a point half way between the two layers was in all cases 10 in. With the exception of the beams in groups 11 and 12 the area of the steel used was nominally 3 square inches; giving for the percentage of steel a value of 3.75%. In the beams of groups 11 and 12 the percentages of steel were lower. Information on the placing of the steel in the beams is given in Table X Summary of Tests. The beams were all made of 1:2:4 concrete with the exception of a small section in the compression area of each beam. This section was made of 1:1:2 concrete, and extended horizontally a distance of 27 inches on each side of the center line of the beam; vertically it extended

to a depth of 4 inches. The purpose of this rich mixture was to prevent premature compression failure at the center.

The beams were designed with so large a percentage of steel to insure diagonal tension failure before the failure on the steel in tension. The concrete proved stronger than was expected due probably to the thorough mixing obtained and the careful attention given to supplying the correct amount of water. As a result most of the failures were due to exceeding the yield point stress of the steel in tension. Reference to table V giving Strengths of Control Cylinders shows the concrete used to be of exceptionally good quality.

7. Forms: The forms consisted of bottomless wooden boxes set upon the concrete floor on top of a sheet of heavy building paper used to prevent adhesion of the beams to the floor. The forms were painted to prevent warping and to prevent absorption of water from the concrete.

8. Fabrication: The steel was first bent to the proper shape, then fastened to the sides of the forms by means of staples and wires. Corks were fastened to the sides of the forms at the proper positions for the gage lines, and the outside bars were held in place by attaching them to the side forms in order to insure their remaining in contact with the corks while the concrete was being placed. The inner bars in the bottom layer were set on small strips of wood. Strips of wood placed across the bottom layer held the bars of the upper layer in place during concreting.

The concrete was mixed in a "Wonder" mixer with a capacity of 7 cu. ft. After first being mixed in the machine mixer, the concrete of four consecutive batches was dumped on the floor and mixed before

TABLE V

COMPRESSIVE STRENGTHS OF CONCRETE CYLINDERS MADE WITH BEAMS

Beam No.	Date		Age	Manner of Storage							
					In Moist Room				With Beams		
	Made	Tested	Days	1-2-4 8x16in.	1-2-4 6x12in.	1-1-2 6x12in.	Ave.	1-2-4 8x16in.	1-2-4 6x12in.	1-1-2 6x12in.	Ave.
16 B1-1	1-19-17	3-20-17 3-19-17	60	3000	2800	4000	2900	2580	2450	3260	2515
16 B1-2	3- 8-17	5- 7-17	60					2910	2670	4030	2790
16 B2-1	1-19-17	3-20-17 3-19-17	60	3000	2800	4000	2900	2580	2450	3260	2515
16 B2-2											
16 B3-1	1-27-17	3-27-17 3-26-17	59	3250	3450	4550	3350	3480	3440	4840	3460
16 B3-2	3- 7-17	5- 7-17	61	3160	3480	4460	3320	3080	3170	4440	3125
16 B4-1 16 B4-2	2-20-17	4-24-17	63	3060	3280	4800	3170	3240	3210	4900	3225
16 B5-1	1-27-17	3-27-17 3-26-17	59	3250	3450	4550	3350	3480	3440	4840	3460
16 B5-2											
16 B6-1 16 B6-2	2-17-17	4-19-17	61	3640	3480	5060	3560	3730	3770	4620	3750
16 B7-1 16 B7-2	2-17-17	4-19-17	61	3640	3480	5060	3560	3730	3770	4620	3750
16 B8-1 16 B8-2	2-24-17	4-26-17	61	3290	3410	4980	3350	3230	3190	5120	3210
16 B9-1 16 B9-2	2- 1-17	4- 2-17	60	3420	3450	4380	3435	2720	3510	5000	3115

16 B10-1 16 B10-2	2- 1-17	4- 2-17	60	3420	3450	4380	3435	2720	3510	5000	3115
16 B11-1 16 B11-2	2- 8-17	4-12-17	63	3720	3810	5580	3765	3510	3590	5330	3550
16 B12-1 16 B12-2	2- 8-17	4-12-17	63	3720	3810	5580	3765	3510	3590	5330	3550
16 B13-1 16 B13-2	2-12-17 3- 6-17	4-14-17 5- 4-17	61 59	3840 3230	3660 3300 3290	5210	3750 3275	3210 3240	3040	4400 5150 5070	3125 3240
16 B14-1 16 B14-2	2-24-17	4-26-17	61	3290	3410	4980	3350	3230	3190	5120	3210
16 B15-1 16 B15-2	2-12-17	4-14-17	61	3840	3660	5210	3750	3210	3040	4400	3125
16 B16-1 16 B16-2	2-14-17	4-17-17	62	3610	3780	5160	3695	3260	3440	4850	3350
16 B17-1 16 B17-2	2-14-17	4-17-17	62	3610	3780	5160	3695	3230	3440	4850	3350
16 B18-1 16 B18-2	2-15-17	4-19-17	63	3100	3650	5120	3375	2890	3330	5350	3110
16 B19-1 16 B19-2	2-15-17 3- 7-17	4-19-17 5- 7-17	63 61	3100 3160	3650 3480	5180 4460	3375 3320	2890 3080	3330 3170	5350 4440	3110 3125
16 B20-1 16 B20-2	2-20-17 3- 6-17	4-24-17 5- 4-17	63 59	3060 3230	3280 3300 3290	4800	3170 3275	3240 3240	3210	4900 5150 5070	3225 3240

TABLE VI

TENSION TESTS OF STEEL FROM BEAMS

Beam Number	Diameter in.	Yield-Point Stress lb.per sq.in.	Ultimate Strength lb.per sq.in.	Elongation in 8 in. Percent	Reduction of Area Percent
16 B3-1	.872	40 900	63 000	28.7	51.8
16 B3-1	.875	42 700	61 100	32.5	57.1
16 B5-1	.877	43 100	64 500	32.5	49.2
16 B5-1	.876	41 700	64 400	28.7	47.1
16 B7-1	.875	41 400	61 600	33.8	58.2
16 B8-1	.880	42 300	60 700	28.7	60.8
16 B9-1	.876	42 400	64 200	30.0	50.7
16 B9-1	.876	40 500	64 000	31.2	60.3
16 B10-1	.877	41 700	64 400	27.5	44.4
16 B10-1	.878	42 000	63 000	31.2	47.4
16 B12-1	.878	50 500	82 200	27.5	45.0
16 B13-1	.872	41 700	64 400	30.0	39.2
16 B15-1	.877	44 800	66 500	27.5	48.2
16 B15-1	.873	40 000	65 200	27.5	48.8
16 B16-1	.875	57 000	78 000	21.2	58.1
16 B16-1	.879	49 800	81 100	22.5	48.4
16 B17-1	.874	46 200	62 000	31.2	58.3
16 B17-1	.872	44 400	65 400	30.0	37.3
16 B18-1	.874	47 600	77 500	31.2	46.9
16 B19-1	.876	55 900	61 200	30.0	58.0
16 B19-1	.878	53 900	60 700	37.5	60.2
Average		45 700	66 300		

TABLE VI. Continued.

Beam Number	Diameter in.	Yield-Point Stress lb.per sq.in.	Ultimate Strength lb.per sq.in.	Elongation in 8 in. Percent	Reduction of Area Percent
16 B14-1	1.010	39 000	48 300	36.2	68.4
16 B14-1	.998	42 000	62 400	32.5	60.5
Average		40 500	55 350		
16 B4-1	.624	37 800	55 300	33.8	64.0
16 B4-1	.625	38 200	56 400	31.2	66.7
16 B6-1	.623	37 800	56 100	30.6	61.2
16 B7-1	.624	36 900	56 400	30.0	68.2
16 B7-1	.624	36 950	58 900	25.0	62.9
Average		37 500	56 600		
16 B2-1	.752	38 700	54 800	32.5	65.3
16 B2-1	.747	41 800	60 100	30.0	64.1
16 B6-1	.755	41 400	60 300	31.2	61.1
Average		40 600	58 400		
16 B11-1	*.624	37 900	55 800	33.8	60.8
16 B11-1	*.623	37 000	57 200	31.2	63.2
16 B12-1	*.626	33 800	56 300	30.0	63.0
16 B12-1	*.624	33 800	56 400	28.8	66.0
16 B13-1	*.625	36 300	58 300	35.0	65.7
16 B13-1	*.624	37 000	57 500	31.2	66.0
Average		36 000	56 900		

*Square bars; all others round.

being placed in the forms. From each four batches mixed thus two beams, always of different groups, were made. The concrete was placed around the bars and tamped; then the forms were filled in layers of about four inches, the concrete being continually tamped and spaded to insure a good dense concrete and to prevent honeycombing.

9. Control Specimens: In addition to the beams, 4 cylinders were made with each beam, two 6 by 12-in. cylinders of the 1:1:2 concrete were made, and two 8 by 16-in. cylinders of the 1:2:4 concrete. One of each of these two sizes was stored with the beam, the other two in the moist-room.

10. Storage: The forms were removed from the beams at the end of seven days. Then the beams and the accompanying cylinders were stored under burlap, which was wetted down two or three times a day, until within a week or ten days of the time for testing. After removing the burlap the sides of the beams were whitewashed, the gage holes were drilled, and the beams were hauled to the testing laboratory for the test.

11. Testing: The tests were made in a four-screw Olsen testing machine having a capacity of 100 000 lb. on the wings designed to carry test beams. With the exception of the cases mentioned under "Notes on Tests" the load was applied with a speed of the crosshead of .04 in. per minute. The general method of transmitting the load from the cross-head to the beams may be seen by referring to the photographs. The test span, center to center of bearings, was 9 ft. 6 in. The distance between load-points was 18 in., leaving 4 ft. from the load-point to support; thus giving the same bending moment

as a beam with a span of 12 feet loaded at the one-third points. With this condition of loading the yield-point stress in the steel was reached in most cases without complete failure of the beam having occurred. In all but a few cases, as soon as the maximum load was reached the test was discontinued and then with the load-points moved 12 in. nearer the supports the load was re-applied. This reduced the moment for a given load to three fourths of its former value and allowed the development of greater shear.

Beams 16 B20-1 and 16 B20-2 both failed completely in diagonal tension before reaching the yield-point of the steel. A second test was made on Beam 16 B20-1 by placing the supports 6 ft. apart and the loads 2 ft. from the supports, or at the one-third points of the span. Most of the tests of previous series at the University of Illinois investigating diagonal tension have been made on beams of 6-ft span loaded at the one-third points. The second test of Beam 16 B20- therefore, gives a basis for comparing certain of these tests with those of previous series.

Usually the load was applied in increments of 10 000 pounds; wherever this was not possible a smaller increment was used. Strain gage readings were taken on gage lines located as shown in the diagrams, Fig. 3a to 24a and in the photographs 34 to 36. The strain gage used for most of the tests is a special form of the Berry strain gage. The instrument is of Invar steel and showed very little change in length due to temperature variations; its gage length was 4 in. and its multiplication ratio is five. On some of the tests an aluminum instrument of the same type but with a multiplication ratio of 7 $\frac{1}{2}$ was used. All beams were tested at an age of 60 days, or as nearly so as possible.

12. Tests of Control Specimens: The compressive strength tests of the control cylinders, and the tensile strength of the reinforcing steel are given in Tables V and VI. Stress-strain diagrams for the control cylinders are given in Fig. 1 and 2.

III. EXPERIMENTAL DATA AND DISCUSSION.

13. Reduction of Data: In reducing the strain gage readings the method used regularly by the University of Illinois Engineering Experiment Station was used. A detailed description of the method for reducing strain gage data can be obtained by referring to Bulletin 64 of the University of Illinois Engineering Experiment Station, "Tests of Reinforced Concrete Buildings Under Load" by Prof. A. N. Talbot and Prof. W. A. Slater.

14. Explanation of Drawings: Fig. 3a to 24a show to a scale of 1 in. = 10 in. the location of the gage lines. Sketches in Table X. show the disposition of the steel in the beams. The cross section shows the lateral position of the steel, while the side views show the locations of the points of bending up of bars. These sketches also show the positions of the load-points and the supports.

15. Explanation of Tables: The tables giving the results of the tension tests of the cement briquettes, tension tests of the steel, mechanical analysis of the sand, mechanical analysis of the gravel, the compression tests of the cylinders are self explanatory. The table giving the summary of the beam tests is intended to condense the results of the tests in so far as possible. Values of the maximum shearing unit-stress, and the maximum tensile unit-stress are given opposite the drawings showing the manner of reinforcing the

beams. These values are given for both conditions of loading, that is, with the load points 18 in. apart and with the load points 3 ft. 6 in. apart. This arrangement allows an easy comparison of the load carried by beams with different disposition of reinforcement. Other tables such as the one giving possible ranges of values of compressive unit-stress, likewise need no explanation.

16. Explanation of Diagrams: The diagrams, Fig. 3b to 24b are load-deformation diagrams for each gage line of each individual beam. Wherever gage lines on opposite sides and opposite ends of the beam are in similar position with respect to the vertical center line, the corresponding load-deformation diagrams are plotted from the same vertical axis but at different heights on the page; this affords a convenient method for comparing the deformations at corresponding points on the beam. Whenever the gage lines are not in similar positions on the beam the curves are plotted from different vertical axes.

17. Explanation of Photographs: The photographs, Fig. 26 to 33 will give some information on the manner of failure of each of the beams, and the extent to which cracks had developed at the time of failure. Fig. 25 shows the manner of applying the load to the beams. Fig. 26 to 33 inclusive show the beams at the time of failure. In Fig. 34 to 36 inclusive the cracks have been marked plainly on the beams, together with the height of these cracks at various stages of loading.

18. Notes on Tests: Beam 16 B1-1. At 6000 lb. no cracks were as yet visible. At 14 000 lb. several small vertical cracks had appeared all within 24 in. of the center line. The largest of these was

on the west side 23 in. north of center and extended to a height of 4 in. At 20 000 pounds nothing important had as yet developed. Small tension cracks were becoming more numerous. At 26 200 pounds all cracks were advancing but inclining somewhat towards load-points. At 32 000 pounds the load was on and all strain gage readings had been taken with the exception of 131 when failure occurred at the north end by a diagonal tension crack opening up from north support to load point. As the failure occurred the stress in the steel at the center fell off from 32 000 pounds per square inch to 17 000 pounds per square inch. The failure was rapid but not instantaneous.

Beam 16 B1-2. At 10 000 pounds no cracks were visible. At 20 000 pounds numerous small tension cracks appeared thruout the length. Most important crack on west side was a small diagonal tension crack 18 inches south of center; On the east side one important crack had appeared 27 inches south of center; this crack extended vertically to a height of 4 inches, then diagonally towards load point for 4 inches more at an angle of about 45 degrees. At 28 800 pounds failure occurred suddenly but not instantaneously, by the formation of a diagonal tension crack which was followed by stripping along bars. This crack first appeared 37 inches south of center and extended towards load points.

Beam 16 B2-1. At 4200 pounds no cracks were noticeable. At 8000 pounds two diagonal tension cracks had appeared on the west side of the beam 26 inches and 35 inches north of the center line. Both of these cracks were inclined at an angle of about 75 degrees after passing the horizontal steel. At 12 000 pounds the cracks previously noted had advanced slightly and another appeared on the west

side 16 inches south of center. This crack inclined towards load points at an angle of about 75 degrees. At 16 000 pounds further development of cracks already noted was slight. A new diagonal crack 38 inches south of center on the west side of the beam inclined at 75 degrees and extended to a height of 5 inches. A similar crack occurred on the east side 39 inches south of center and inclined at 60 degrees to a height of 6 inches. At 20 000 pounds a new diagonal crack had opened up to a height of 7 inches; this crack appeared on the west side 33 inches south of center and inclined at 45 degrees. The crack at 38 inches south of center was stationary. Similar new crack on east side 33 inches south of center. At 24 000 pounds new cracks had formed at 45 degrees and joined to the old cracks which had flattened out considerably and extended towards load points.

Beam 16 B3-1. At 10 000 pounds several vertical cracks 3 to 4 inches high were found all within 20 inches of the center. At 15 000 pounds diagonal cracks had appeared outside the points of bending up of bars; these crakks extended to a height of about 6 inches and were inclined at an angle of about 65 degrees. At 20 000 pounds cracks were becoming more numerous. The cracks were more general and further developed than in beam 16 B5-1 at the same load. No marked change in cracks and no very large cracks at 25 000 pounds load. At 30 050 pounds diagonal cracks had developed still further, inclining more towards load points. More diagonal cracks were in evidence at north end of beam but beginning to develop rapidly at the south as well. The tension cracks at the center were practically stationary. At 35 000 pounds the diagonal cracks towards end of beam, (north end in particular) were inclining more towards load points at a flat

angle. At 39 300 pounds the load was going on very slowly and it was noticeable that the stress in the upper layer of bars was increasing faster than that in the lower layer. No reason for this was apparent. At 39 500 pounds the load fell off and examination showed slipping of bars of about $\frac{1}{40}$ of an inch in upper gage hole of gage line 222. At 39 700 pounds the load again fell off due to continued slipping at the above point, and slipping at gage hole 122. Crack 8 $\frac{1}{2}$ inches from north support, and inclined directly to support was rapidly opening up. The maximum load was 39 700 pounds. Failure was due to insufficient bond or anchorage of the inclined bars, the bars slipping and allowing diagonal tension failure. It was principally in the second bar from the north end that slip occurred.

Beam 16 B3-2. At 10 000 pounds a few small tension cracks from 1 to 2 inches high had appeared. All of these were within 24 inches of the center line. At 20 000 pounds the most noticeable crack was a diagonal tension crack just outside gage line 332. It extended vertically to the horizontal steel then inclined at an angle of 45 degrees for about 6 inches. On the east side of the beam diagonal tension cracks had appeared just outside point of bending up of bars. The worst one was 15 inches north of south support extending diagonally across gage line 121. Similar crack at north end but not so well developed. At 30 000 pounds diagonal tension cracks were becoming more numerous. Tension cracks at the center were practically stationary. On the west side of the beam a large diagonal tension crack opened up just inside of south gage hole of 431 and extended diagonally to gage line 422. At the south end of the beam the most evident crack was one previously noted at 20 000 pounds as just out-

side gage line 332; This crack opened up considerably. On the east side of the beam the same general tendencies of cracks were noticed as on the west side. The most noticeable cracks were one thru gage line 121 at the south end, inclined at an angle of 45 degrees to within 4 inches of the top. Another starting at gage line 131 and extending diagonally to within 4 inches of the top at an angle of about 60 degrees. At 35 000 pounds the most noticeable development was on the west side of the beam near the south end where diagonal tension crack noted at 20 000 and 30 000 had spread out along the horizontal steel for about 3 inches. On the east side cracks had developed at the north end along the inclined bar from gage line 231 to 221. No similar cracks at south end. On the west side at the south end a crack was noticeable along the inclined bar from gage lines 331-321. There was no similar crack at the north end. At 42 100 pounds there was an extension of diagonal tension cracks nearest the ends crossing gage lines 121, 221, and 331. Deformation in lower bars at the center was increasing less rapidly than in upper bars (same as was observed in the case of beam 16 B3-1). Along diagonal bar a crack appeared from south gage hole of 431 to south gage hole of 421. This apparently is the maximum load with the load points 9 inches from the center on each side of the center line. The load was then removed and the load points moved to positions one foot nearer the supports. Load was re-applied with high speed up to 42 000 pounds, then with high speed lever and friction clutch engaged. Maximum load came while running on this rather high speed at a load of 44 600 pounds. Failure was at south end by diagonal tension which seems to have been caused by slipping at end of bent up bar on which

gage lines 131 and 121 were located. The principal crack was across the center of gage line 121.

Beam 16 B4-1. At a load of 10 000 pounds there wereno cracks. At 20 000 pounds a few tension cracks,generally small, had appeared scattered along the length of the beam on both sides. At 30 000 pounds the most noticeable crack was a vertical crack outside the last bend on the east side, north end extending to a height of almost 6 inches. At 40 000 pounds the steel at the center had passed the yield-point at gage lines 161 and 361. A diagonal crack was advancing from a tension crack at 342. The total crack was about 10 inches long. Upper part of crack made an angle of about 30 degrees with the horizontal. Cracks in general were advancing from previous cracks and opening up slowly. At 41 600 pounds the steel had not passed the yield-point in any of the gage lines at the first and second points of bending up of bars. Scaling of steel was noticed in both layers of bars at the center of the span. Initial failure was entirely by tension at the center. Diagonal tension cracks beginning to develop more extensively especially from the tension cracks at the points of bending up bars. After this load had been reached the load fell off to 38 500 pounds in about 3 minutes. The load was then removed and the load points moved one foot nearer the supports. At 49 500 pounds the steel had passed the yield-point at gage lines 141 and 241 and at 342 and 442. Diagonal tension cracks were developing but they were not extensive enough to be responsible for failure. Load was going on very slowly. At 53 000 pounds very large cracks were present under both load points. Both cracks inclined about 70 degrees with the horizontal and sloped away from

load points. The south end developed compression at load point finnally, but both failures were primarily tension failures. This was an exceedingly tough beam, holding load near maximum for some time.

Beam 16 B5-1. At 10 000 pounds the small tension cracks distributed over the central portions of the beam were all that were in evidence. At 20 000 pounds cracks opened up to gage holes at gage lines 32, 42, 34, and 44. At 30 400 pounds there seems to be a difference of cracks on the opposite sides of the beam as shown in sketch on page . On the west side 31 inches south of center there was a crack 8 inches high at an angle of 45 degrees. At 35 100 pounds there were few new cracks, but mainly continuation of old ones. Failure occurred by tension in steel at center. The load was allowed to remain on all night. At 7:30 in the morning the load had fallen off to 34 150 pounds. The load points were shifted one foot nearer to the supports and the load re-applied. This brought the load points just outside the first point of bending up of bars. The maximum load with the load points in this position was 52 800 pounds. Failure apparently was due to failure of steel in tension in bottom layer of bars just outside first point of bending up of bars.

Beam 16 B6-1. At 10 000 pounds only small tension cracks were noticeable at central portion of beam. One diagonal crack developed to a height of about 5 inches at an angle of 60 degrees with the horizontal, and crossing gage line 442. At 20 000 pounds the principal cracks of importance were tension cracks although small diagonal cracks had appeared, two on the east side 18 inches and 22 inches north of center line and inclined at an angle of 65 degrees with the horizontal and extending to a height of about 5 inches; one on the

west side across gage line 432, inclined at an angle of 75 degrees and extending to a height of about 5 inches. At 30 000 pounds the small tension cracks had become generally distributed thruout the length of the beam; some of them branching off into diagonal cracks. New diagonal tension crack across gage line 231 extended to a height of about 6 inches. Similar crack across 441 at an angle of 60 degrees extended 7 inches high. Large diagonal crack at 45 degrees crossing gage lines 132 and 142 extended to a height of about 8 inches. At 40 000 pounds nothing new of much importance except that diagonal cracks as previously noted had extended considerably. The most extensive advance was in crack crossing gage line 142 which had opened to a width of about .02 inch. At a load of 40 700 pounds the maximum load was reached, and was due to the failure of the steel at center. The crack across 142 had opened extensively though and probably was a contributing cause. The load fell off at this point to 37 400 pounds in a few minutes. The load points were then moved to a point one foot nearer the supports, and the load was re-applied. A maximum was reached at 54 500 pounds, failure occurring by tension in the steel just outside bent-up bars nearest the center. At gage hole 142 this crack was particularly evident.

Beam 16 B7-1. At 10 000 pounds no cracks were evident. At 20 000 pounds cracks were found on the west side of the beam between gage lines 42 and 41 at both ends; these cracks had developed to a height of about 8 inches. Cracks thru gage lines 42; cracks less prominent on the east side than on the west. At 30 000 pounds a prominent crack appeared at gage line 242, starting out at an angle of about 45 degrees and flattening out to about 20 degrees at the top.

At 40 000 pounds the prominent crack previously noted at 242 had extended to the load point. The steel had passed the yield point in gage lines 161, 242, 361, and 341, but the deformation was largest in 242. At 42 200 pounds the maximum load was reached. The cracks had about the same appearance as at 40 000 but the deformation was now larger in 161 than 242. The failure was evidently by tension, though diagonal tension may have been a contributing factor. From the development of the crack from 242 to load point, this last method of failure seems quite a likely one. The load points were then moved out one foot and the load re-applied; a maximum was reached at 56400 pounds. Failure by compression began just inside north load point. No very large tension cracks were present. Diagonal tension cracks were most prominent, but still the yield point of the steel had been passed in gage lines 432 and 442. The deformation at 432 was higher than at 442 probably because 432 was crossed by a diagonal tension crack.

Beam 16 B8-1. First noteworthy cracks appeared at a load of 20 000 pounds. These were merely small tension cracks, the largest ones being just outside the first points of bending up of bars. At 30 000 pounds the previous tension cracks were advancing slightly and developing into diagonal tension cracks. The average height of these was about 8 inches and their angle about 70 degrees. The tension cracks at the center were advancing very slowly. At 40 000 pounds a crack began spreading along the bent up bar at gage line 242, and a diagonal tension crack advanced from this point toward load point to within 3 inches of the top of the beam. General advance of diagonal tension cracks occurred on both sides of the beam

the angle of the crack flattening, and the crack advancing towards the load points. During the test the load fell off to 37 400 pounds, and from there on took load very slowly. At 40 800 pounds the maximum load was reached. Failure was by tension in the steel at the center of the span. The load points were then moved to a point one foot nearer the supports. After passing 52 000 pounds the beam began to take load more slowly. This beam held a load near the maximum for some time, showing considerable toughness. This failure too was due to failure of the steel in tension, but this time the failure occurred just outside the points of bending up of bars nearest the center. Indications of crushing appeared just inside new load-point at north end of beam.

Beam 16 B9-1. At 10 000 pounds only one small vertical crack had appeared. At 20 000 pounds several small tension cracks were found at the center. A pronounced crack had appeared on the west side 19 inches north of support and a similar one at the north end of the beam. On the east side similar cracks were in evidence, but they were much less pronounced. At 30 000 pounds the cracks near the ends were more prominent on the west side than on the east side. This was probably due to the fact that the distance from the support to the first bend on the west side was 23 inches, while on the east side it is 17 inches. At 32 900 pounds the load fell off suddenly and a large crack appeared about 10 inches north of south support; this crack extended to a height of about 9 inches and inclined at an angle of about 60 degrees with the horizontal. At 40 000 pounds the yield point of the steel was reached at the center. At 41 000 pounds a diagonal crack opened up on the east side 19 inches north of center and inclined at an angle of 45 degrees. At 41 900 pounds the

maximum load was reached. Primary failure was by tension at center of span at about 41 900 pounds. Failure was followed by compression failure at about 41 900 pounds. Failure in tension near south end outside of points of bending up of bars, must have been imminent judging from the size of the cracks.

Beam 16 B10-1. At a load of 10 600 pounds cracks of an unusual nature parallel to the direction of the bent up reinforcing bars were found. One extending from the north gage hole of 441 along the inclined bar to the lower gage hole of 431. A similar crack was found from 341 to 331. At 20 000 pounds the cracks above noted had continued along gage lines 131, 231, 331, and 431. The crack from 131 to 141 had just appeared at this load. At 30 000 pounds the cracks outside of the bent up bars had become prominent generally. Those particularly noticeable were one 16 inches north of south support and one 8 inches south of north support on the east side. On the west side the general tendencies were the same as on the east side, the large cracks were in approximately the same position relative to the support, the only difference being that they were less pronounced. The cracks at the south end were almost vertical while those at the north end were inclined at an angle of about 50 degrees with the horizontal. At 36 300 pounds failure occurred apparently by tension in the reinforcment outside of the point of bending up of bars at the north end. Along with the tension failure diagonal cracks opened and became the most pronounced cracks in the beam; the opening of the diagonal cracks and stripping of bars occurred along the horizontal position in the top of the beam close to the north end. Cracks also followed around the U hooks of the thru bars.

Beam 16 B11-1. On the west side of the beam about the quarter point on the south end the concrete had not filled out well against the form, leaving large openings around the bars. At 13 400 pounds few cracks were visible. At 20 000 pounds on the east side at the north end of the beam a prominent crack had appeared; it started 12 inches south of north support and extended diagonally at an angle of 60 degrees to a height of about 7 inches. Numerous small tension cracks were in evidence. At 30 000 pounds the stress in the steel at gage hole 161 was 36 000 pounds per square inch; in 361 it was 43300 pounds per square inch. There was general but slight advance of tension cracks. At 35 100 pounds it was evident that the maximum load was near, for the beam was taking load very slowly and at gage lines 161 and 361 the indicated stress was 73 500 and 88 800 pounds per square inch respectively, indicating that the steel there had passed the yield-point. The load had fallen off to 33 000 pounds. At 35 100 the maximum load was reached. Failure before additional load was applied was due to failure of the steel in tension at the center. The load-points were moved one foot nearer to the supports, and the load re-applied. With this new addition of loading failure occurred at 48 850 pounds. At this load the strain gage readings showed high stress in the steel at gage lines 141, 142, and 133. At 341 the indicated stress was 94 000 pounds per square inch. While it is not possible that any such stress existed there, the indication is that the steel there had passed the yield-point. The steel at 441 had also passed the yield-point for the deformation here had passed the range of the instrument. A possible explanation for the steel stress being higher on the west side than on the east side lies in the

poor quality of the concrete around the bars on the west side. The honey-combed nature of the concrete probably forced the steel to take most of the stress from a very low stage of loading. This failure was evidently due to tension failure of steel at gage lines 341 and 441. The tension failure was followed by crushing of the concrete at the top.

Beam 16 B12-1. At 10 000 pounds comparatively few cracks had appeared. Most of these were small tension cracks. One small diagonal tension crack had appeared and extended from gage line 141 to gage line 132. At 20 100 pounds several small diagonal tension cracks had appeared, but none had developed to a serious extent. At 30 000 pounds a diagonal tension crack opened up 35 inches south of center, inclined at 70 degrees and extended to a height of 9 inches. Cracks were well distributed and more nearly vertical than usual. None of the cracks seemed tobe opening up to any great extent. At 35 000 pounds at north end of beam, 7 inches south of support, a large diagonal crack developed, inclined at 60 degrees and extended across inclined bars. At 36 700 pounds the maximum load was reached with the load points 18 inches apart. Failure was due to tension in steel at the center. Scaling of bars was noticed at gage lines 161, 361, and 162. In a few minutes the load had fallen off to 34 300 pounds. The load points were moved out one foot and the load reapplied. At 45 000 pounds the stress in the steel at gage line 131 was 35 000 pounds per square inch. A crack about 9 inches high had suddenly appeared 35 inches south of center, thru south gage hole of gage line 131. At a load of 45 100 pounds the load was going on very slowly. From the appearance of the crack 35 inches south of center

the steel at that point must have passed the yield point. Maximum load was reached at 46 700 pounds. Failure was due to tension at center and probably tension failure at large crack at south end. Crushing of concrete followed.

Beam 16 B13-1. At 10 200 pounds no cracks were visible. At 20 100 pounds most of the cracks which had developed were vertical tension cracks which ranged in height from 3 inches to 6 inches.The largest of those on the west side crossed gage line 441. There was another crack at 341. On the east side the same general tendencies were noted with the exception that the crack across 141 had developed into a diagonal tension crack inclined at an angle of 45 degrees, and extending to a height of 5 inches. At 30 000 pounds the vertical cracks were becoming larger. Most noticeable cracks extend across gage lines 42. The previously noted tension cracks were starting to extend diagonally towards the load points. One diagonal tension crack opened up from gage line 431 at an angle of 30 degrees. At 38 600 pounds the yield point of the steel at the center had been passed. Scaling of bars was noticed at gage line 361. The steel at the second point of bends was either past or close to the yield point. At 40 600 pounds the maximum load had been reached. The tension crack at the center had opened up to a width of about .04 inches. The steel had passed the yield point at the second points of bending up. Failure was by tension in the steel at the center. At the gage lines 42 tension failure had probably occurred also. The tension failure was followed by crushing in concrete.

Beam 16 B13-2. At 10 000 pounds a few small tension cracks had appeared within the central portion of the beam. At 20 000 pounds a

number of vertical cracks ranging from 5 to 6 inches in height opened up on both sides of the beam. Small diagonal tension cracks appeared on both sides of the beam, all within 35 inches of the center. The most noticeable was one crossing gage lines 341 and 332 at an angle of 60 degrees; this crack extended to a height of 6 inches. At 30 000 pounds the vertical cracks had extended somewhat and those outside the load points were inclining towards the load points.Most noticeable crack was 18 inches north of south support where crack inclined at an angle of 70 degrees extended to within 4 inches of the top. At 39 700 pounds the steel at the center had passed the yield point. Two new cracks inclined at about 60 degrees had appeared just outside of bends (gage lines 341, 441). On the east side a large crack inclined at an angle of 70 degrees with the horizontal, extended to gage line 132, and after crossing the bar continued at an angle of about 25 degrees to within 3 inches of the load point. At 40 100 pounds the maximum load was reached. Failure was due to tension in steel at center; there was a high stress in the steel at gage line 341 which may have been a contributing cause of failure. The load points were then moved one foot nearer to the supports and the load re-applied. At 51 600 pounds the maximum load was reached, failure due to tension in steel outside bends at 442 and 441 judging from the appearance of the cracks. A large vertical crack extended vertically to gage line 432 and then out along the bar. The vertical crack just outside gage line 442 had opened to a width of about .05 inch. Following the tension failure at gage line 431 a diagonal crack extended at an angle of 30 degrees and flattened out to load point. Crushing of concrete followed just outside of load point.

Beam 16 B14-1. At 10 000 pounds only four cracks were found and these were within 30 inches of the center. All were tension cracks and the largest was only four inches high. At 20 000 pounds numerous tension cracks were in evidence thruout the length of the beam. Three of the four cracks mentioned at 10 000 pounds had developed into diagonal tension cracks inclined at an angle of 60 degrees and extending to a height of about 8 inches. On the west side one crack near the south end turned away from the load point and along the inclined bar. At 30 000 pounds an important crack appeared on the east side 10 inches from the north support. This extended vertically to the steel then at 40 degrees with the horizontal above the bar and to within 4 inches of the top. Similar cracks were noticed at the other end of the beam and on the opposite side. Up to 37 800 pounds load the beam had been taking load regularly, but here the load fell off. Cracks were found at the north end on east side as shown on drawing locating gage lines. Indications were that no slipping at the end of bar (gage line 221; 231) had taken place. The yield point of the steel had been passed at 231. The load fell off here to 34 600 pounds in a few minutes. On re-applying the load the beam took the load slowly (using fast speed of the machine) up to a load of 39 200; with the slow speed of the machine the load went on so slowly that the tension cracks at the center were opening up considerably. Failure at this load was due to tension at center, and just outside bends. The load points were then moved out one foot towards the supports. The largest cracks at the center did not close up appreciably. Upon re-applying the load no marked change in the cracks was noticed until the maximum load was reached. The failure

occurred suddenly by cracks nearly horizontal opening up near the north end; this was accompanied by cracks around the loop opening up and permitting complete failure. Failure at this load was due to tension at center and outside of bends accompanied by diagonal tension and splitting around the hook at the north end.

Beam 16 B15-1. At 10 000 pounds only two vertical tension cracks were found; both on west side and each were 22 inches from the center and 5 inches high. At 20 000 pounds two new cracks were found on west side 32 inches and 31 inches respectively from the center inclined at an angle of 60 degrees, and extending to a height of 8 inches. Cracks were beginning to become more generally distributed. On the east side of the beam two cracks similar to those on the west side were found. At 24 000 pounds the four cracks noted at 20 000 pounds had begun to open slightly and flatten load points. A new crack appeared on the west side 8 inches from the north support, inclined at an angle of 50 degrees to within 2 inches of the top. Similar crack occurred at the south end but not so extensively developed. At 36 000 pounds slip of bar was noticed at gage hole 421 and 221. At 40 000 pounds the new cracks noted at 24 000 pounds had flattened to about 25 degrees and extended towards load points. The one at the north end had opened up appreciably and extended to the top of the beam. The load fell off to 37 400 pounds in a few minutes. Upon re-application of the load slip was noticed at 422 and 222. Maximum load was reached at 41 000 pounds. Failure occurred due to tension failure near end. This was closely followed by diagonal tension failure and splitting around hook.

Beam 16 B16-1. At 10 000 pounds only one small crack was found

a little north of gage hole 161. At 20 100 pounds the most prominent cracks were about 6 inches high, and appeared between the first and second bends; these cracks were nearly vertical, but at the top inclined slightly towards the load points. A vertical crack extended up to the south gage hole of gage line 432 and from there inclined along the bar for 2 $\frac{1}{2}$ inches. At 30 000 pounds long cracks had developed at the outer gage hole of gage line 131 and 231, inclined at an angle of about 75 degrees with the horizontal. Fairly large cracks had appeared between gage lines 232 and 242. The crack noted at 20 100 pounds as running along the inclined bar had now extended to the north gage hole of 432. At 35 000 pounds there were no marked changes in the appearance of the cracks, and the steel at the center was not stressed beyond its yield point. At 40 000 pounds the highest stresses about 46 000 lb. per sq. in. were outside the load points at gage lines 141 and 342. At 44 600 pounds the beam had reached its maximum load. The largest steel deformations had shifted from outside the load points to the center of the beam. No cracks had appeared outside of gage line 131, 231, 331, and 431. Failure was due to tension in steel at center. The steel at gage line 141 and 342 also near the yield point. Evidence of crushing following the tension failure appeared on the east side at the center, and above gage lines 332 and 342. These evidences of crushing did not appear until after the machine had been stopped. The load fell off at 40 200 pounds at this stage in a few minutes. The load points were shifted to a position one foot nearer the supports and the load reapplied. Load was carried up to 51 600 pounds when failure occurred apparently by tension in steel between first and second point of

bending up of bars. This was accompanied by crushing just outside the north load point.

Beam 16 B17-1. At 10 000 pounds no cracks had appeared. At 20 000 pounds the only cracks worthy of note were those about 30 inches from each end on both sides. These cracks were vertical and extended to a height of about 6 inches. At 30 200 pounds strain gage readings showed high stress in the steel at the south end. At 35 900 the largest vertical cracks were about 15 inches and 39 inches respectively from the north end. Diagonal crack had appeared at the south end, and extended from gage line 141 towards load point; this crack was beginning to open up considerably. The steel at gage line 141 was beyond the yield point. At 38 200 pounds the beam had reached the maximum load. Failure was due to tension in the steel just outside the second bend; this was closely followed by diagonal tension failure and crushing of concrete at the top. Beam proved very tough maintaining a load near the maximum for a long time without much apparent opening of cracks.

Beam 16 B18-1. No cracks at a load of 10 200 pounds except one very small one at the center. Stress on the east side higher in gage lines 141 and 241 than in 142 and 242. On the west side higher in 342 and 442 than in 341 and 441. At 20 000 pounds the stresses at all gage lines 41 and 42 were about the same, about 9000 to 10000 pounds per square inch. The highest cracks were within 18 inches of the center and extended vertically to a height of 7 inches. At 30000 pounds cracks had appeared about 10 inches from the support at each end; these cracks were about 8 or 9 inches high and inclined from 60 to 75 degrees with the horizontal. At 40 000 pounds typical diag-

onal tension cracks developed from all the gage lines 42 and extended to load points. At 45 500 compression failure began to appear just inside the north load point. The machine was stopped and crushing had progressed for a few seconds when failure in diagonal tension occurred suddenly in a crack that had first appeared at 39 400 pounds. This crack had been opening up considerably, and just previous to failure was the largest crack in the beam. Strain gage readings showed that the yield point of steel had been passed at gage lines 242, 232, and 241, but at no other places. Failure was due to tension in the steel outside the first and second bends, accompanied by diagonal tension failure.

Beam 16 B19-1. At 10 000 pounds there were very few cracks. All these weretension cracks and mainly between the load points. None were over 3 inches high. At 20 000 pounds the most noticeable cracks were at the gage lines 32. These cracks were about 6 inches high and inclined at an angle of 75 degrees. At 30 000 pounds cracks had appeared on both sides at each end within about 14 inches of the supports, inclined slightly and extending to a height of about 8 inches. All these cracks just were outside the last bend. At 40 000 pounds cracks at the gage lines 32 were advancing and opening. The stress in the steel at the gage lines 32 was comparatively low in cracks noted at 30 000 pounds. The steel at the center had passed the yield point. None of the diagonal steel was stressed beyond 30 000 pounds per square inch. Failure at this point was due to tension in the steel at the center, the steel at the first bend also had high stress. The load had fallen off to 37 700 pounds in a little less than 15 minutes. The load points were moved one foot

nearer the supports and the load reapplied. At 51 000 pounds the steel at the gage lines 41 had passed the yield point. The load fell off to 47 600 pounds in 10 minutes. Upon reapllication of the load the beam took the load very slowly, finally attaining a maximum at 52 000 pounds. Failure was due to tension at the center and just at the 41 gage lines.

Beam 16 B19-2. At 10 000 pounds no cracks had appeared. At 20 000 pounds several small tension cracks had appeared on each side of the beam. All of these cracks were within 30 inches of the center with the exception of one just outside gage line 141. This crack progressed vertically to the steel, then along the inclined bar to north gage hole of gage line 131. One diagonal crack 6 inches high was inclined at 45 degrees on the west side, and 3 feet south of north support. At 30 000 pounds a crack had appeared just outside the bend at gage line 441, extended vertically to the bar than along the inclined bar for 3 inches. Crack corresponding to one noted at load of 20 000 pounds appeared on the opposite side of beam at the same end. Diagonal crack appeared at this load 6 inches from south support extending to south gage hole of gage line 131. Diagonal crack from north gage hole of 141 to within 1 inch of 132. Large tension crack 12 inches south of north support extending vertically to lower gage hole of gage line 231. At 40 000 pounds the most noticeable crack was a diagonal one extending from gage line 141 at an angle of 50 degrees to within 5 inches of the top; similar crack on west side, north end. All cracks in the outer portion of the beam inclining more towards the load points. The steel at the center had passed the yield point. The load had fallen off in a short while to

37 200 pounds. At 41 100 pounds the maximum load was reached. Little further development of cracks previously noted. Failure was by tension on steel at center. The load points were now moved one foot nearer the support, and theload reapplied. At 54 100 pounds the maximum load was reached. Failure eas due to tension in steel at first bend, followed by compression. Beam very tough holding load near maximum for some time.

Beam 16 B20-1. At 10 000 pounds load no cracks were visible. At 20 000 pounds a number of small tension cracks had appeared scattered thru the central portions of the beam and ranging from 4 to 6 inches in height. On the east side 30 inches and 36 inches respectively south of center two diagonal tension cracks had appeared and extended to a height of 6 inches and 4 inches. At 28 800 pounds a diagonal tension crack suddenly appeared on the east side 42 inches south of center and extended at an angle of 45 degrees to a height of 8 inches. Another appeared on the east side at 28 800 pounds 27 inches south of center, and extended to a height of 6 inches at an angle of about 70 degrees. At this load small diagonal tension cracks had become general. Stress in steel at this load 33 000 pounds per square inch. At 31 000 pounds the maximum load was reached. Failure by diagonal tension came suddenly and without warning.

Beam 16 B20-2. This beam apparently was mishandled in bringing it to the testing laboratory, for before any load was applied a crack was noticed 9 inches north of the center of the beam clear across the top and to a depth of about 5 inches. At 10 000 pounds only three cracks were visible and two of these were tension cracks 9 inches and 11 inches north of center respectively, which joined to

the crack previously noted at zero load. The crack found at zero load though still visible, apparently had closed somewhat. At 20 000 pounds, diagonal tension cracks had opened up at north end of beam on both sides; one 24 inches north of center and extending at an angle of 60 degrees with the horizontal to within 4 inches of the top, and one at 36 inches north of center extending at an angle of 70 degrees clear to the top. At 25 000 pounds the cracks were not extended. At 29 600 pounds the maximum load was reached. There was no sign of approaching failure. The failure was due to diagonal tension, and was closely followed by stripping along bars. The crack causing failure extended diagonally from the north load point to 2 feet south of north support. Stripping was continuous to the support.

19. Discussion of Results: The highest load carried by any beam in which no bars were bent up was less than the lowest load carried by any beam having bars bent up for web reinforcement. For the beams with no bars bent up, failure was by diagonal tension in all cases. For the beams having bars bent up, failure was by tension in the steel in all cases with the possible exception of Beam 16 B3-1 and Beam 16 B3-2 in which slipping of some of the bent up bars at their ends played an important part.

Reference to the summary of tests, Table X shows that in all the beams with inclined bars, regardless of the manner of bending up angle of bends, spacing of the points of bending, or anchorage, the maximum shearing unit-stress developed varied only from 272 to 362 lb. per sq.in. when the loads were 18 in. apart and 358 to 445 lb. per sq.in. when the loads were 3 ft. 6 in. apart. This result would follow from the fact that failure was by tension in all these beams.

However, the distribution of stress varied slightly, bars in certain locations taking stress somewhat faster than those in others, and it is from a standpoint of stress in the inclined reinforcement rather than from one of the maximum shearing unit-stress developed, that the results of these tests will have to be discussed.

(a) Beams with Straight Bars not anchored:- The beams with straight bars and no U-hooks were first tested on a 9-ft. 6-in. span with two equal loads each 9 in. from the center and 4 ft. from the end. Later a test was made on beam 16 B20-1 on a 6-ft. span with loads at the one-third points. In this case the loads were 24 in. from the supports, half as great distance between load and support as in the first test of the same beam. Failure was by diagonal tension in both cases. The shearing unit-stress developed was 248 lb. per sq.in. in the first test and 348 lb. per sq. in. in the second test, an increase of 40%. Judging from previous tests of beams 6 ft. long loaded at the one-third points of the span a shearing strength of possibly 225 lb. per sq.in. would be expected from beams with so large a percentage of reinforcement. The fact that in the second test of beam 16 B20-1 the shearing strength was 55% greater than this indicates that the concrete was of a better quality than usual. The high strength of the concrete probably is largely responsible for failure of so many of the beams by tension in the steel instead of by diagonal tension.

(b) Beams with U-Hooks and no Bars Bent Up: Of the beams having the same area of longitudinal reinforcement those having straight bars carried nearly the same loads as those with U-hooks and no bars bent up. In the beams with U-hooks the hooks were just coming into action at the maximum load, indicating that the deformation along the bars was sufficient to allow diagonal tension failure to occur without the

hooks becoming effective. Beam 16 B2-1 which had 27% less reinforcement than 16 B1-1 and -2 carried 13% less load than the average for 16 B1-1 and -2.

Although none of these beams failed by tension in the steel those with the smaller amount of reinforcement carried the smaller load indicating that the load at which diagonal tension failure occurs is a function of the deformation along the reinforcement.

(c) Effect of Angle of Bend upon location of Maximum Stress in Inclined Members: Beams 16 B11 16 B12 and 16 B13 were made with the intention of studying the effect of angle of bend upon the web resistance of the beam. The same amount of reinforcement,(2, $\frac{5}{8}$-in. square bars,) was bent up at each point; unfortunately a $\frac{7}{8}$-in. round bar was used in the beams of the 16 B13 group for the thru bar, while in beams 11 and 12 the rod running straight thru was $\frac{5}{8}$ in. square. Table VII will serve to show a comparison of the stress distribution in the inclined members of the different beams.

TABLE VII

STRESSES IN HORIZONTAL PORTIONS NEAR BEND AND IN VERTICAL PORTIONS OF INCLINED BARS AT LOAD OF 30 000 POUNDS.

Beam Number	Angle of Bend Degrees	Stress at Second Bend		Stress at First Bend		Percentage Excess Second Bend over First. Horizontal.
		Horizontal	Inclined	Horizontal	Inclined	
16 B11-1	28	29 400	23 100	25 800	10 500	15
16 B12-1	35	26 700	18 300	24 300	9 600	10
16 B13-1	45	25 700	13 500	19 500	10 100	32
16 B13-2	45	22 500		15 900	5 400	41

From the foregoing table it is evident that highest stress, ex-

cept between the load points, occurred at the bottom of the second bend from the center of the span. This proved true regardless of the angle of bending up. For the given load the percentage excess of the stress in the second bend over that in the first was more for the 28 degree angle, than the 35 degree angle but less than that for the 45 degree angle. This may be affected somewhat by the additional amount of steel running straight thru in the beams with the 45 degree angle of bend. It may also be affected by the fact that the first bend was always in a bar of the upper layer and that the second bend was always in a bar of the lower layer.

A comparison of values given in Table VIIindicates that the stress in the inclined portion of the bars was in all cases less than the stress in the horizontal portion of the same bars near the bend. The difference between the stress in the inclined portion and the horizontal portion was greater, the greater the angle with the horizontal. Table VII also indicates that the stress in the inclined portion of the bars, at the second bend was greater in each case than the stress at the inclined portion of the first bend, the bend nearest the load point. This was true whether the measured stress at the first bend was close to the bottom of the beam or at about mid-height on the beam.

This examination seems to justify the conclusion that greater stress reduction occurs at the bend when the angle of bend in the bar is large, than when the angle of bend is small. The difference between the rate at which the bars took stress at low loads and at high loads, near the bends, was greater for the large angles of bend than for the small angles; that is, the stress-strain curve for the flatter angles of bend has nearly a constant slope while those for the larger angles have considerable curvature.

(d) Effect of the Number of Bars Bent Up at a Given Point: In beam 16 B4-1 and 16 B5-1 two tenths of the total area of the reinforcement was bent up at each of four places. The points of bending were the same in the two cases, but in beam 16 B4-1 two bars($\frac{5}{8}$-in. round) were bent up at each place while in 16 B5-1 only one bar ($\frac{7}{8}$-in. round) of the same area as the two $\frac{5}{8}$ in.rounds was bent up at each place. The test data permit comparison of stresses when one bar is bent up with the stresses when two bars of the same total area are bent up. Beams 16 B13 and 16 B14-1 admit of similar comparison . Table VIIIgives this comparison. It will be seen that in the case of beams 16 B4-1 and 16 B5-1 higher stresses were developed when only one bar was bent up than when two bars of the same total cross-sectional area were bent up at corresponding places. This seems rather unexpected for with the smaller bars the reinforcement is better distributed thru the web. However, the results of the comparison of beams 16 B13 and 16 B14 contradict the results indicated by beams 16 B4-1 and 16 B5-1 and within the range of the tests then it may be concluded that there is little difference in the effectiveness of bent up bars whether one bar or two bars of the same cross-sectional area are bent up at a given place.

(e) Stresses in Bars at Top of Beam: Deformations measured in the horizontal portion of the bent up bars at the top of the beam indicate that little tension was carried thru from the bottom of the beam to that point. For the bars bent up near the load points considerable compression was developed in the horizontal portion at the top of the beam. For bars bent up near the supports very little stress, either tension or compression, was taken at the early stages of the test.

TABLE VIII

EFFECT ON STRESS OF NUMBER OF BARS BENT UP AT THE SAME POINT

Beam Number	Gage Lines	Average Stress	Location
16 B4-1	342 442	26 200	Second Bend
16 B5-1	143 243	28 800	Horizontal
16 B4-1	241 141	20 700	Third Bend
16 B5-1	342 442	29 600	Horizontal
16 B4-1	531 431	14 800	Fourth Bend
16 B5-1	131 231	25 800	Horizontal
16 B13-1	143 243 343 443	19 300	First Bend
16 B14-1	142 242	15 500	Horizontal
16 B13-1	142 242 342 442	27 000	Second Bend
16 B14-1	342 442	23 000	Horizontal
16 B13-1	132 232 332 432	13 800	Second Bend
16 B14-1	332 432	12 000	Inclined

Note: The loads considered in this table were:

Beams 16 B4-1 and 16 B5-1, 40 000 lb.

Beams 16 B13-1 and 16 B14-1, 30 000 lb.

At the higher loads the direction of the load deformation curve frequently was reversed, indicating that slip was taking place at one of the gage holes. There is no indication,however, that the amount of load carried was in any case affected by this slip. In beams 16 B3-1 and -2 no hooks were furnished the inclined bars, and the slip at their ends seems to have hastened failure. In both these beams it seemed that the bars near the ends were the ones most affected.

(f) Effect of Amount of Steel Bent Up on Stress Developed: In beams 16 B5, 16 B6, 16 B7, and 16 B8 one bar was bent up at each of four points, 9.6 in. apart, the first point being 9.6 in. from the load point. The size of the bars was varied, the proportion of the total amount of reinforcement bent up at each point varied as indicated in Table IX . Within the range covered by these tests no difference can be detected in the amount of stress in the bent up bars due to varying the proportion of the total amount of reinforcement bent up. As has been pointed out elsewhere the stress in the inclined portion of the bars was in all cases less than the stress in the horizontal portion near the bend. Although the stress in the horizontal portion of the bar near the bend passed the yield point of the steel in a number of cases in these four beams, there was only one gage line on the inclined portion of a bar in which the stress reached the yield point.

Conclusion: From the results of these tests it seems probable that for a simple beam designed for uniform load all the web stresses which can be developed before tension failure in the longitudinal steel takes place may be resisted by bent up bars provided that the bars are small enough to permit of a sufficient number of

TABLE IX

EFFECT OF AMOUNT OF STEEL BENT UP ON STRESS DEVELOPED AT LOAD OF 30 000 POUNDS

Beam Number	Portion of Area Bent up at Each Point	First Bend Gage Line	First Bend Stress	Second Bend Gage Line	Second Bend Stress	Third Bend Gage Line	Third Bend Stress	Fourth Bend Gage Line	Fourth Bend Stress
16 B5-1 Horizontal.	0.2	444	24 000	143	17 500	442	23 000	131	23 000
		344	18 000	243	15 000	342	13 000	231	15 000
			21 000		16 200		18 000		19 000
16 B5-1 Inclined		434	12 500	133	10 000	432	15 000		
		334	11 000	233	11 000	332	13 000		
			11 200		10 500		14 000		
16 B6-1 Horizontal.	0.102	442	25 000	142	18 000	441	18 000	131	8 000
		342	26 000	242	17 500	341	26 000	231	11 000
			25 500		17 800		22 000		9 500
16 B6-1 Inclined		432	13 000	132	8 000	431	16 000	121	4 000
		332	11 000	232	10 000	331	12 000	221	5 000
			12 000		9 000		14 000		4 500
16 B7-1 Horizontal.	0.101	442	16 000	142	17 000	441	7 000	131	11 000
		342	24 000	242	20 000	341	24 000	232	13 000
			20 000		18 500		15 500		12 000
16 B7-1 Inclined		432	12 000	132	5 000	431	10 000	121	2 000
		332	17 000	232	13 000	331	17 500	221	2 500
			14 500		9 000		13 750		2 200
16 B8-1 Horizontal.	0.149	442	18 000	142	17 500	441	16 000	131	14 000
		342	18 000	242	18 000	341	16 000	231	14 000
			18 000		17 750		16 000		14 000
16 B8-1 Inclined		432	10 000	132	8 000	431	10 000	121	7 500
		332	11 000	232	11 000	331	17 000	221	3 000
			10 500		9 500		13 500		5 250

Note: In column headed Beam Number, "Horizontal" indicates a position on horizontal portion of bar near bend, and "Inclined" indicate a position of the bent up portion of the bar.

bends and provided that all bars are adequately anchored. For most cases it seems likely that these results can be obtained with from 3 to 6 bars in the beam.

The possibility is recognized that for a poorer concrete a different result might have been obtained.

20. Summary:

(1) The beam tests and cylinder tests showed that the concrete used was exceptionally good. This probably accounts for the few diagonal tension failures.

(2) All the beams with the bars bent up and anchored carried a higher load than any beam in which the bars were not bent up.

(3) The shearing strength was considerably greater when the distance between the load-point and the support was 2.4 times the depth than when tested with the load-point 4.8 times the depth from the support.

(4) In beams with U-hooks but with no bars bent up the anchorage was just beginning to come into effect at the maximum load.

(5) In beams with bars bent up at three points the middle bend took the most stress regardless of the angle of bend. However, the fact that the middle bend was from the lower layer probably influences this result.

(6) In no case did the stress in the inclined portion of the bent-up bar exceed that in the horizontal portion of the same bar at the foot of the bend.

(7) The reduction in stress along the bends of the reinforcing bars was greater the larger the angle of bend.

(8) The stress in the inclined bar was not appreciably different

whether two bars or one were bent up at a given point, provided that the same proportion of the horizontal reinforcement was bent up in both cases.

(9) Very little stress was carried thru by the inclined portion of a bar from the bottom of the beam to the top, and there is no indication that in any of the hooked bars the anchorage was not thoroughly effective, although slight local slipping evidently was present.

(10) The stresses in the bent up bars seemed to be independent of the proportion of the total amount of longitudinal reinforcement bent up at each point.

TABLE X

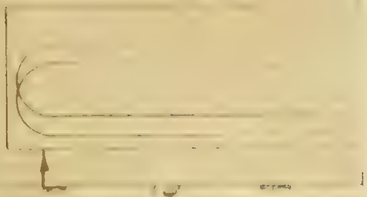
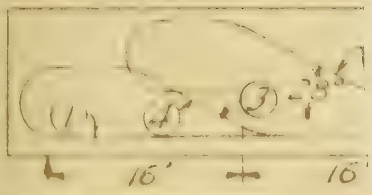
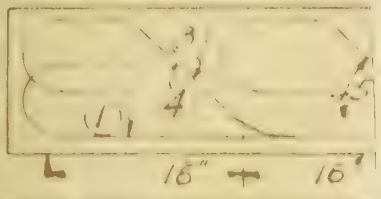
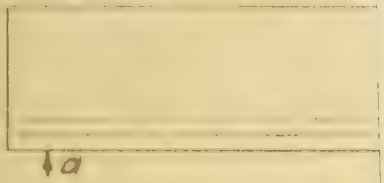
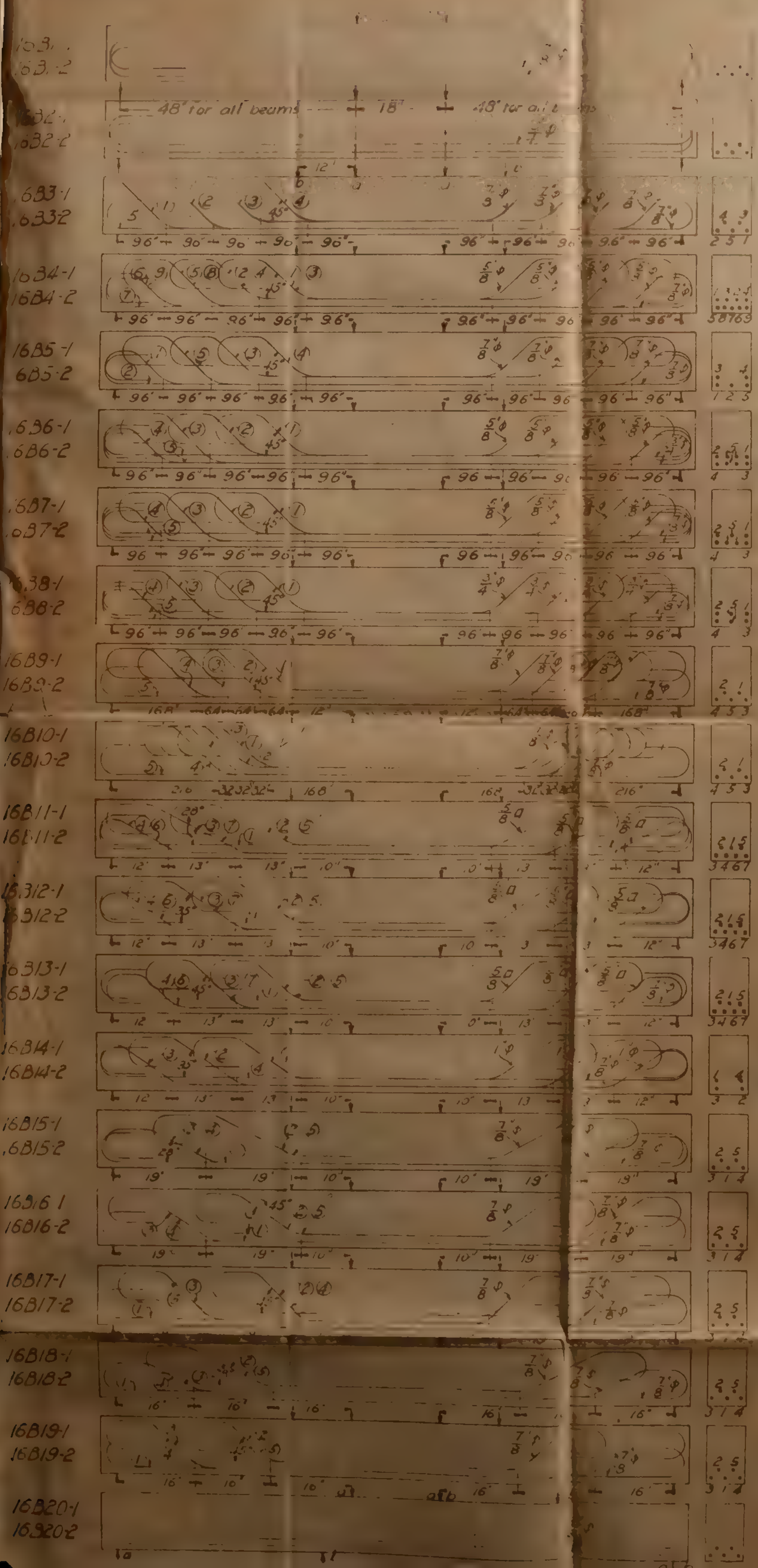
16B1-1 16B1-2	
16B18-1 16B18-2	
16B19-1 16B19-2	
16B20-1 16B20-2	

TABLE X SUMMARY OF BEAM TESTS



[illegible]

TABLE X Con[illegible]ued

Beam Number	Steel Area A_s sq in	Av Meas Width b in	Reinforcement Ratio A_s/bd	Ratio Bent-up to Thru Area	Maximum Load lb a	b	Computed Str[illegible] Load. lb. [illegible] Shear a	b		at Max. in. b	Manner [illegible] a - Loads 18" apart loads 3'-6" apart
16B1-1	3.00	8.20	.0365	0	32000		251		0		(a) D.T., Failure crack from support to load point
16B1-2	3.00	8.08	.0372	0	28800		230		2 0		(a) D.T. & stripping
16B2-1	2.20	8.00	.0275	0	26650		210		36		(a) D.T.; Near Y.P. at center
16B3-1	3.00	8.00	.0375	.800	39700		320		409		(a) D.T.; Failure hastened by slipping of unanchored bar near end of beam & near Y.P. at center.
16B3-2	3.00	8.03	.0375	.800	42100	44600	338	358	434	34500	(a) T. at center. (b) D.T. caused by slipping of third bent-up bar.
16B4-1	3.06	8.03	.0382	.800	41600	53000	335	426	42	40400	(a) T. at center. (b) T. at center & at second and third bends followed by compression
16B5-1	3.00	8.16	.0368	.800	41400	52800	327	417	426	40800	(a) T. at center. (b) T. in lower bars at center and near all bends followed by compression
16B6-1	3.00	8.16	.0368	.409	40200	54500	318	431	415	42300	(a) T. at center. (b) T. at center. Tension cracks small near ends
16B7-1	3.03	8.16	.0371	.405	42200	56400	333	445	431	43200	(a) T. at center & at 1st & 2nd bends Latter probably due to D.T. (b) T. followed by compression. D.T. cracks prominent.
16B8-	2.96	8.13	.0365	.601	40800	55900	323	443	426	43800	(a) T. at center. Tension high at first bend (b) T. at center and under N. load point
16B9-1	3.00	8.15	.0368	.800	41900		331		4310		(a) T. at center & 1st & 3rd points of bending, south of center
16B10-1	3.00	8.02	375	.800	36300		292		374		(a) T. at N. end. Y.P. in lower bars at center DT cracks large.
16B11-1	2.73	8.25	.0332	.859	35100	48850	272	379	394	41100	(a) T. at center & at 2nd bend (b) T. at center & outside of load points, mainly at second bends. Crushing followed
16B12-1	2.73	8.08	.0339	.859	36700	46700	291	370	412	39300	(a) T at center & at 2nd bend (b) T at center. Tension cracks large near S. end. Compression followed
16B13-1	2.95	8.16	.0362	.795	40600		320		425		(a) T. at center and at second bend, followed by compression.
16B13-2	2.95	8.20	.0361	.795	40100	51600	315	406	420	40500	(a) T. at center: high stress at 2nd bend (b) T. at 1st & 2nd bends followed by D.T.
16B14-1	2.96	8.10	.0366	.798	39200	43600	312	347	410	34200	(a) T. outside of bends and at center. (b) T. outside of bends & at center. D.T. & splitting around hook.
16B15-1	3.00	8.08	.0372	.800	41000		328		423		(a) T. near end followed by D.T. & splitting around hook
16B16-1	3.00	8.13	.0369	.800	44600	51600	353	408	460	40000	(a) T. at center and at first bend (b) T. at center and at first bend. Crushing followed
16B17-1	3.00	8.07	.0372	.800	38200		305		39[illegible]0		(a) T. at second bend Crushing and DT. followed
16B18-1	3.00	8.10	.0370	.800	45500		362		469[illegible]0		(a) T. at first & second bends accompanied by D.T.
16B19-1	3.00	8.25	.0364	.800	37700	52000	294	405	388	[illegible]0100	(a) Y.P. at center. High tension at first bend. Max. load not reached. (b) T. at center & at second bend
16B19-2		8.17	.0367	.800	41100	54100	324	426	424	41900	(a) T. at center. (b) T. at first bend, followed by compression.
16B20-1	3.00	8.05	.0373	0	31000		248	349	3200		(a) D.T.; large crack from support to load point (b) D.T.; large crack from support to load point.
16B20-2		8.12	.0370	0	29600		236		3060		(a) D.T. & stripping.

LOAD DEFORMATION CURVES
OF CYLINDERS FOR BEAMS 16B 11-1
AND 16B 12-1

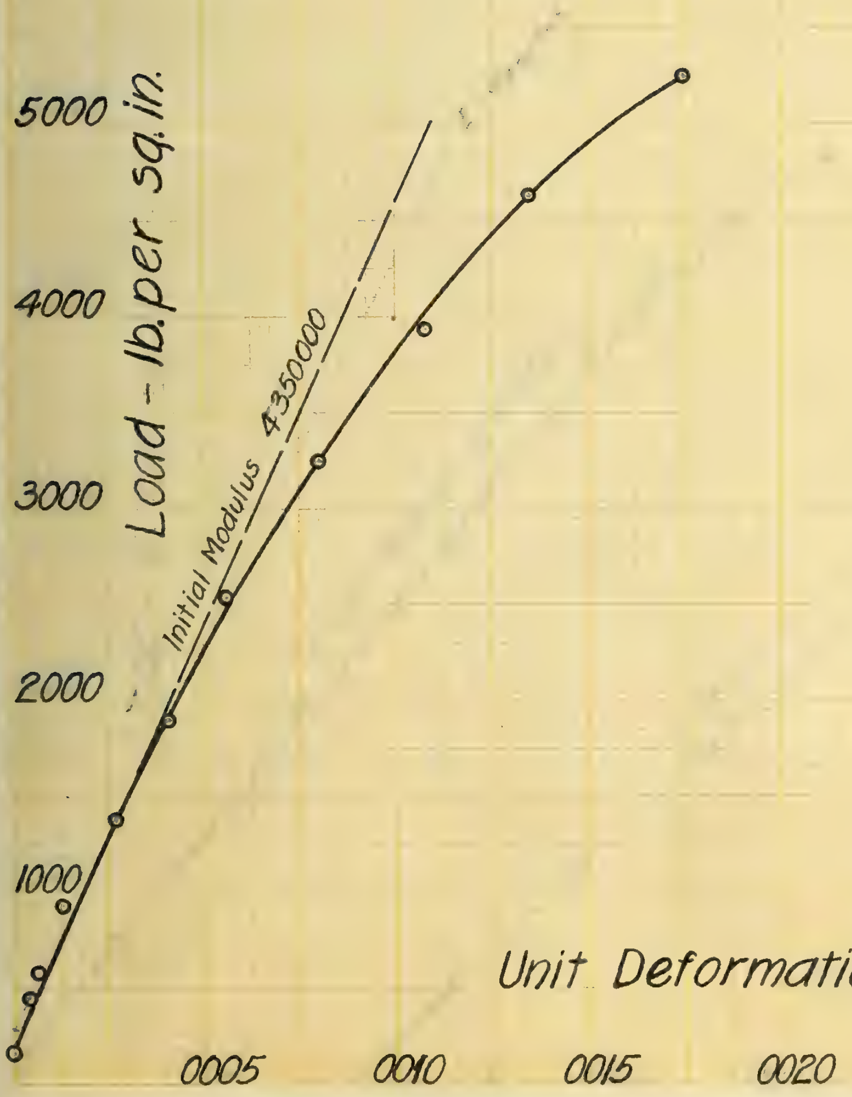


Fig. 1.

LOAD DEFORMATION CURVES OF CYLINDERS FOR BEAMS 16B13-2 AND 16B20-2

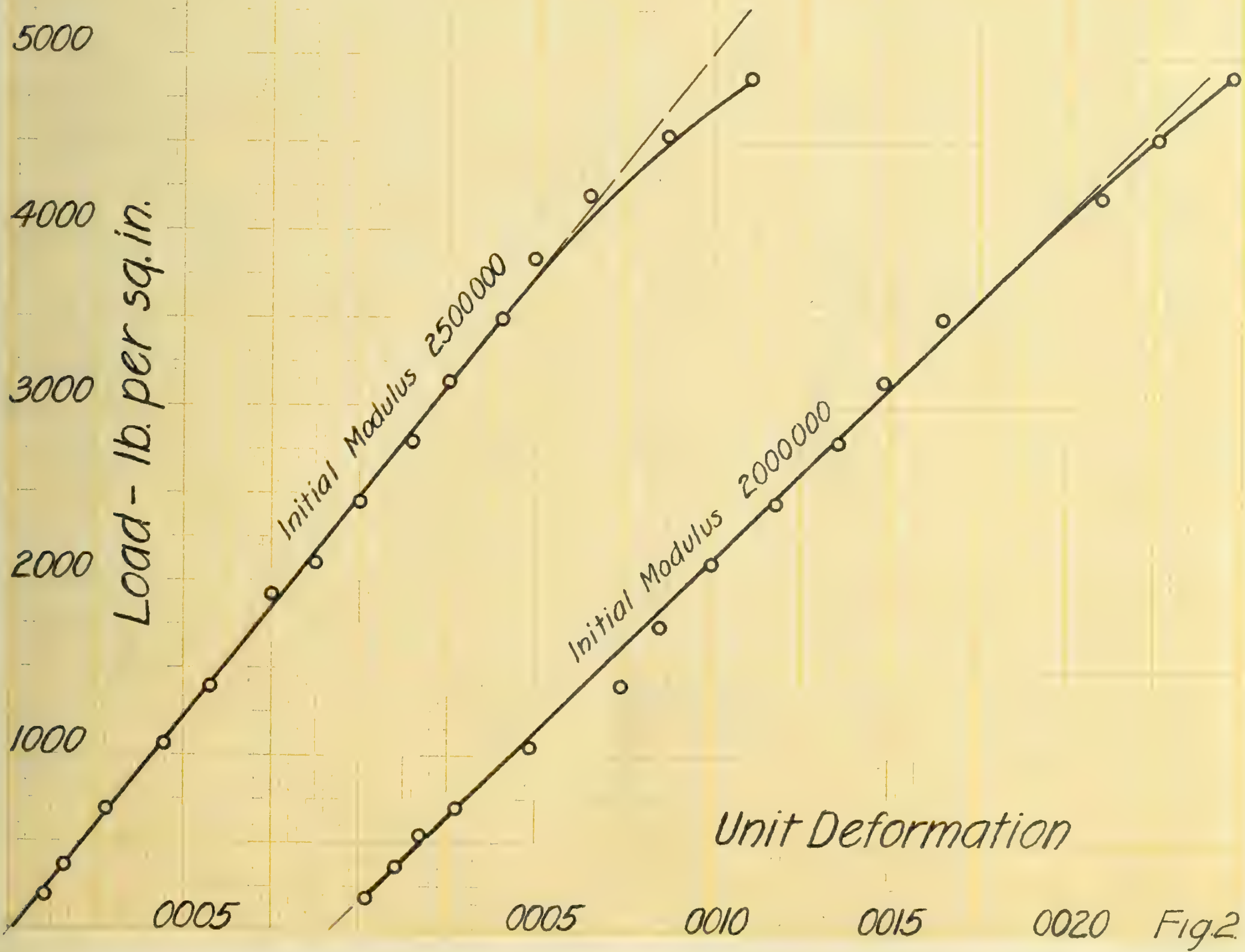
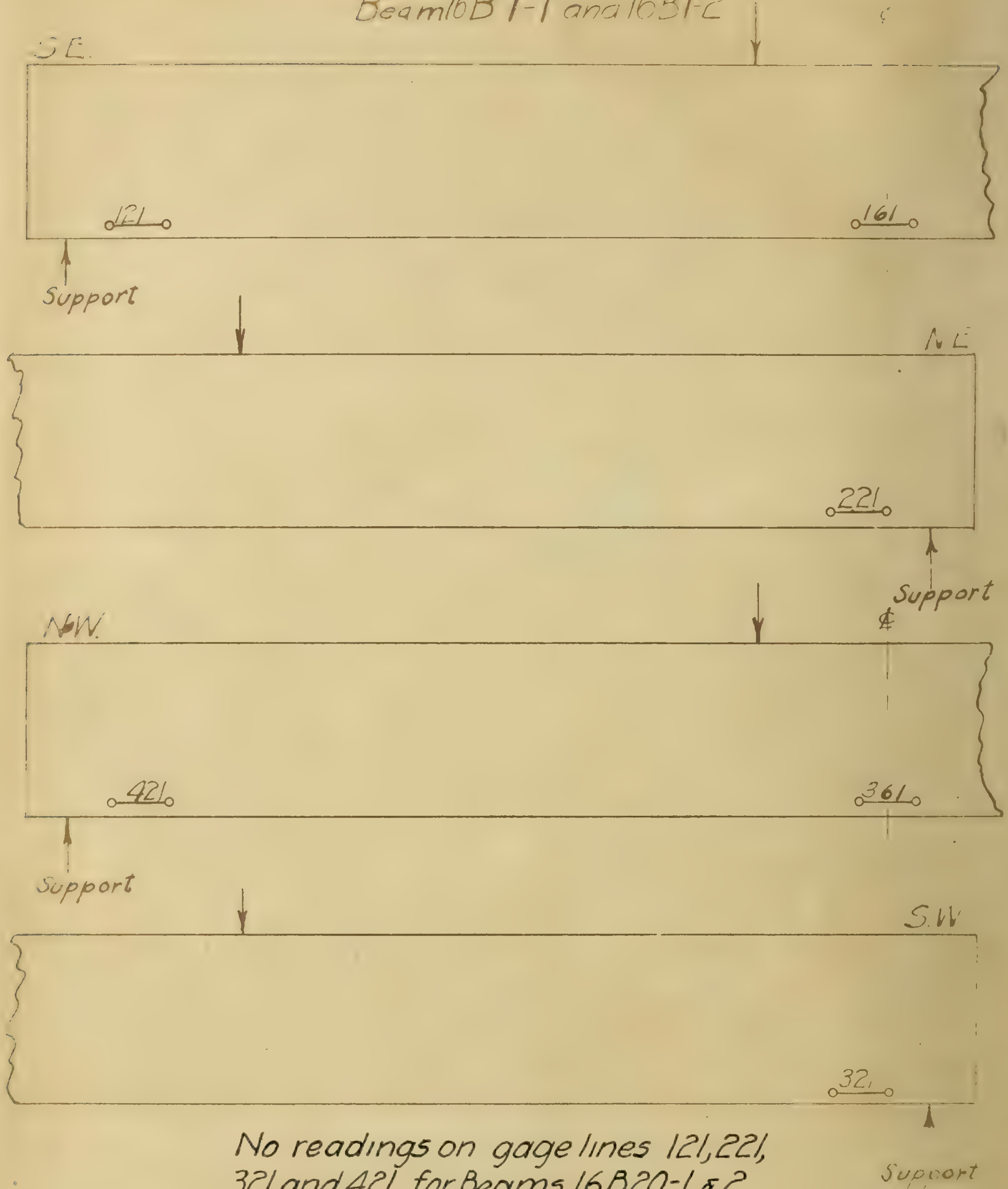


Fig. 2

Beams 16B20-1, 16B20-2
and
Beam16B 1-1 and 16B1-2



No readings on gage lines 121, 221, 321 and 421 for Beams 16B20-1 & 2

Fig. 3a

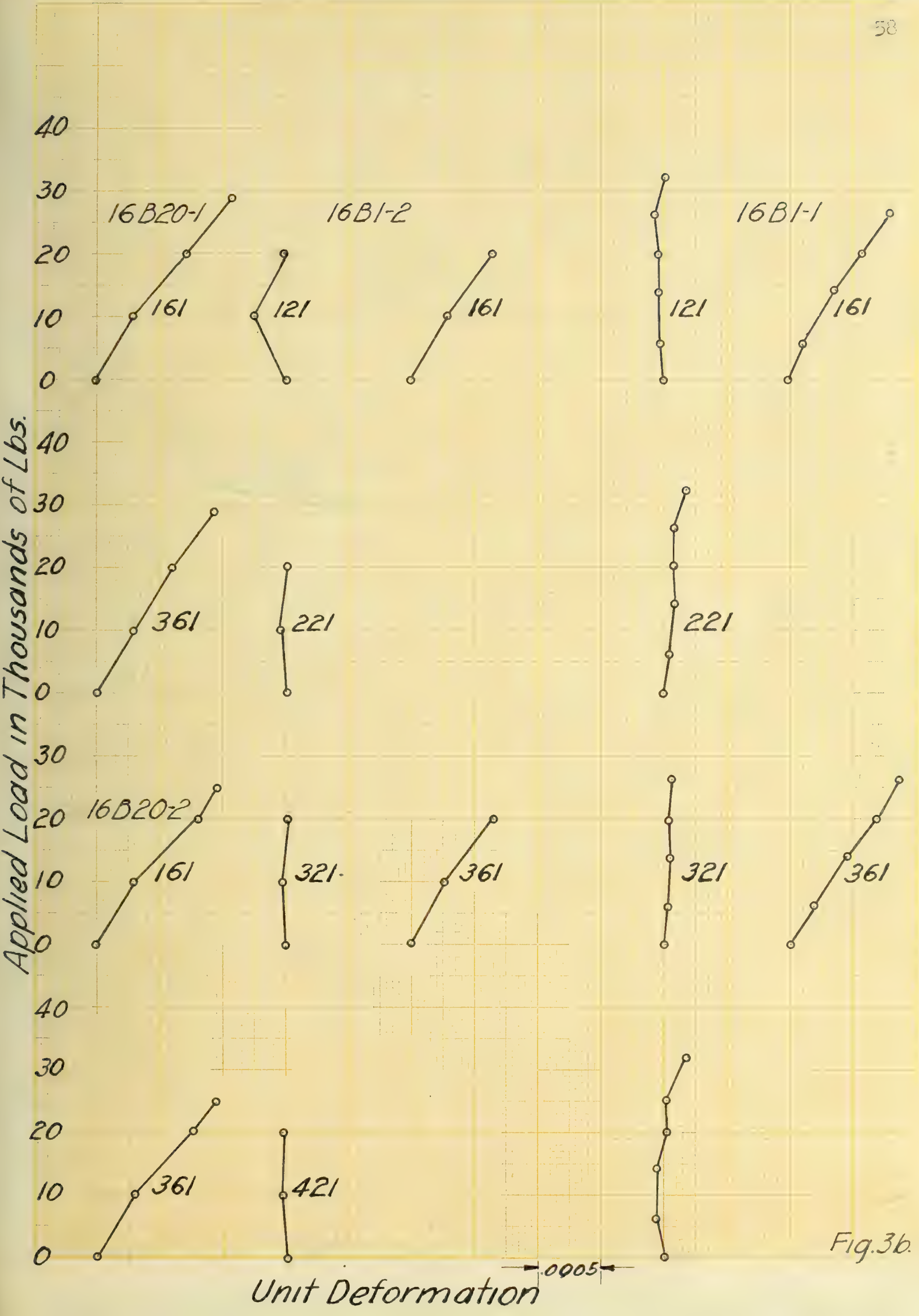

Applied Load in Thousands of Lbs.
40
30
20
10
0
40
30
20
10
0
30
20
10
0
40
30
20
10
0
16B20-1
16B1-2
16B1-1
161
121
161
121
161
361
221
221
16B20-2
161
321-
361
321
361
361
421
.0005
Unit Deformation

Fig.3b.

Beam 16B2-1

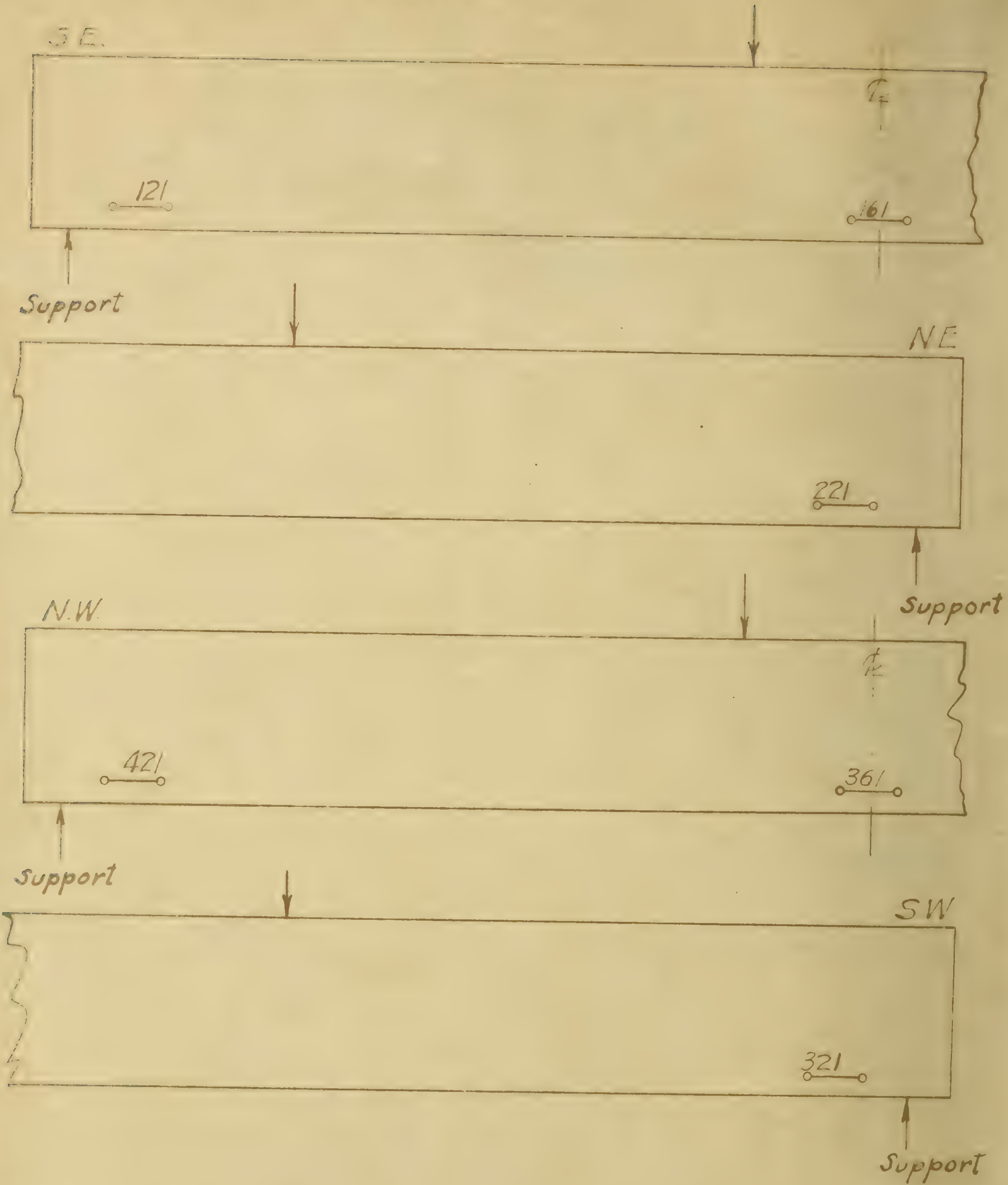


Fig.4a

Beam 16 B2-1

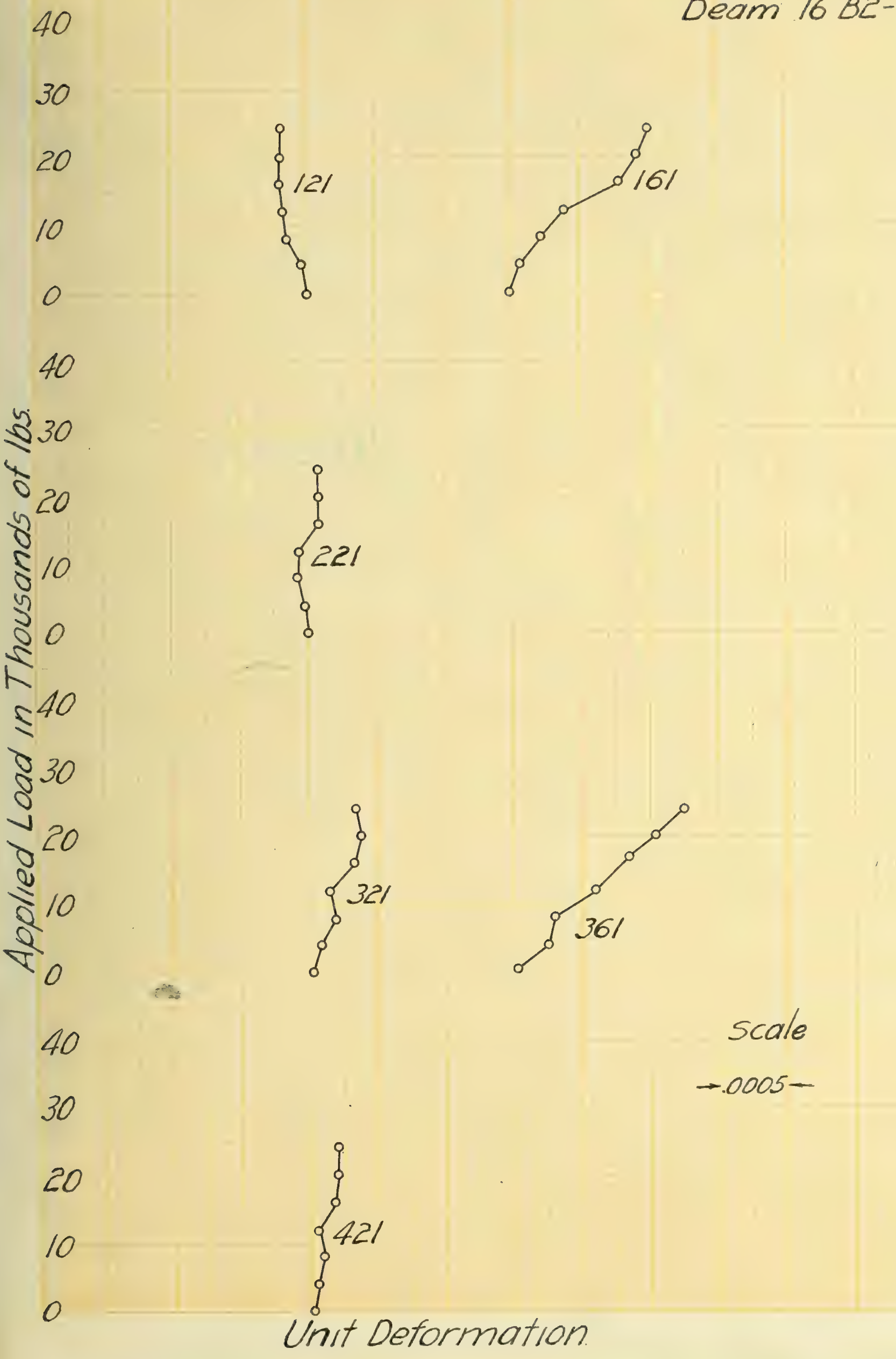
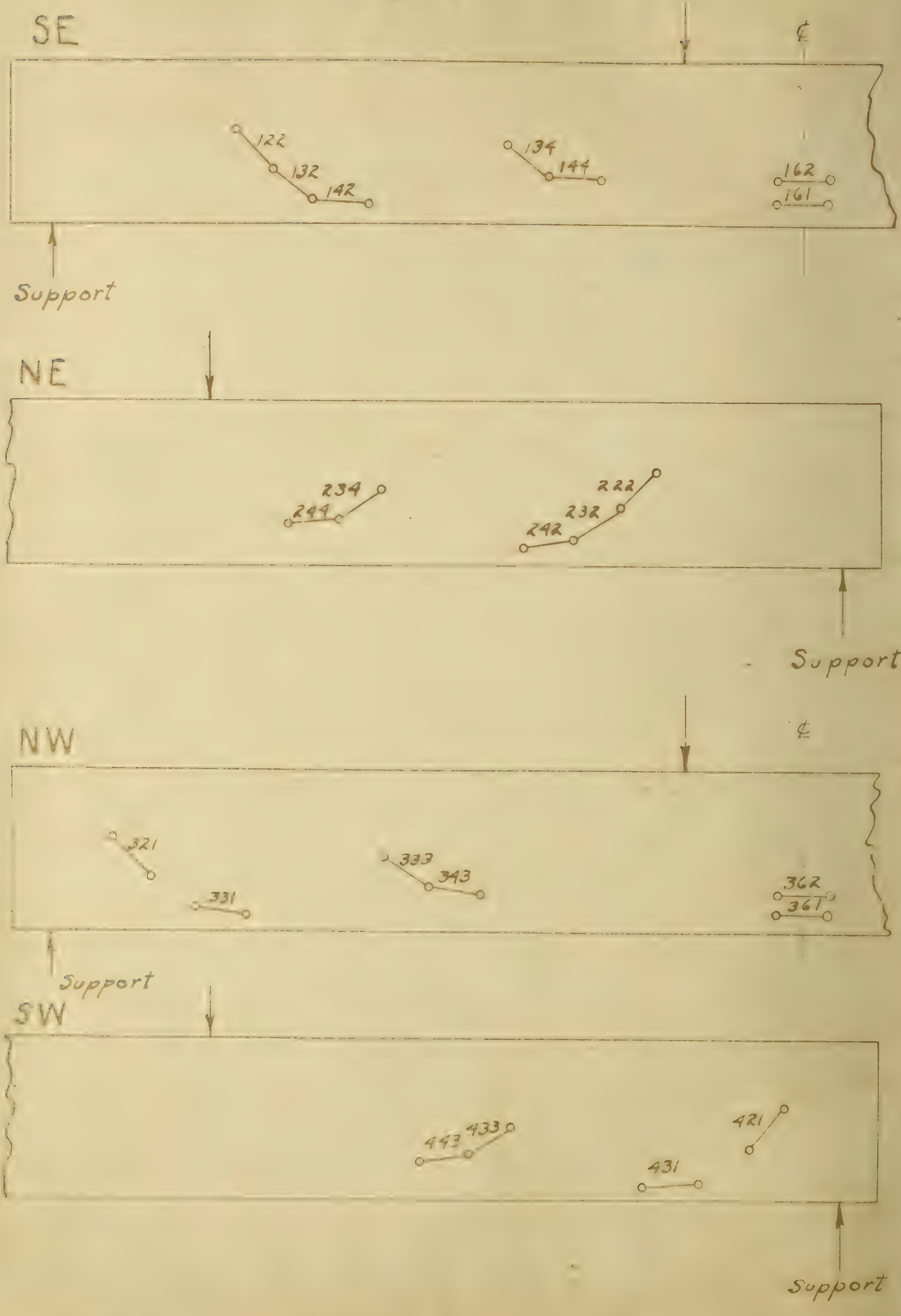


Fig.4b

16-B3-1


SE
℄
Support
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Support
NW
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SW
Support

Fig. 5a

Beam 16 B3-1

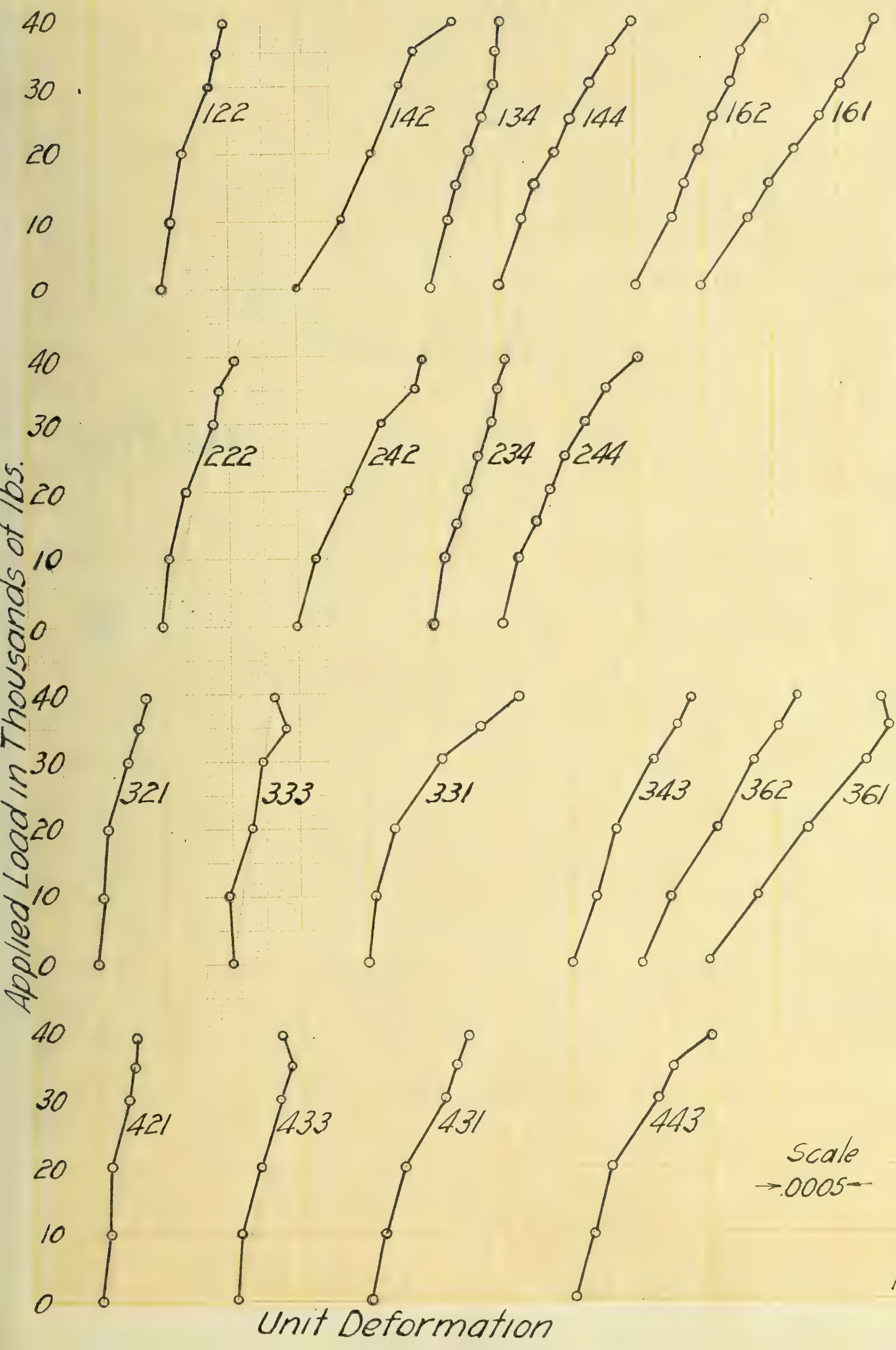


Fig. 5b.

Beam 16B3-2

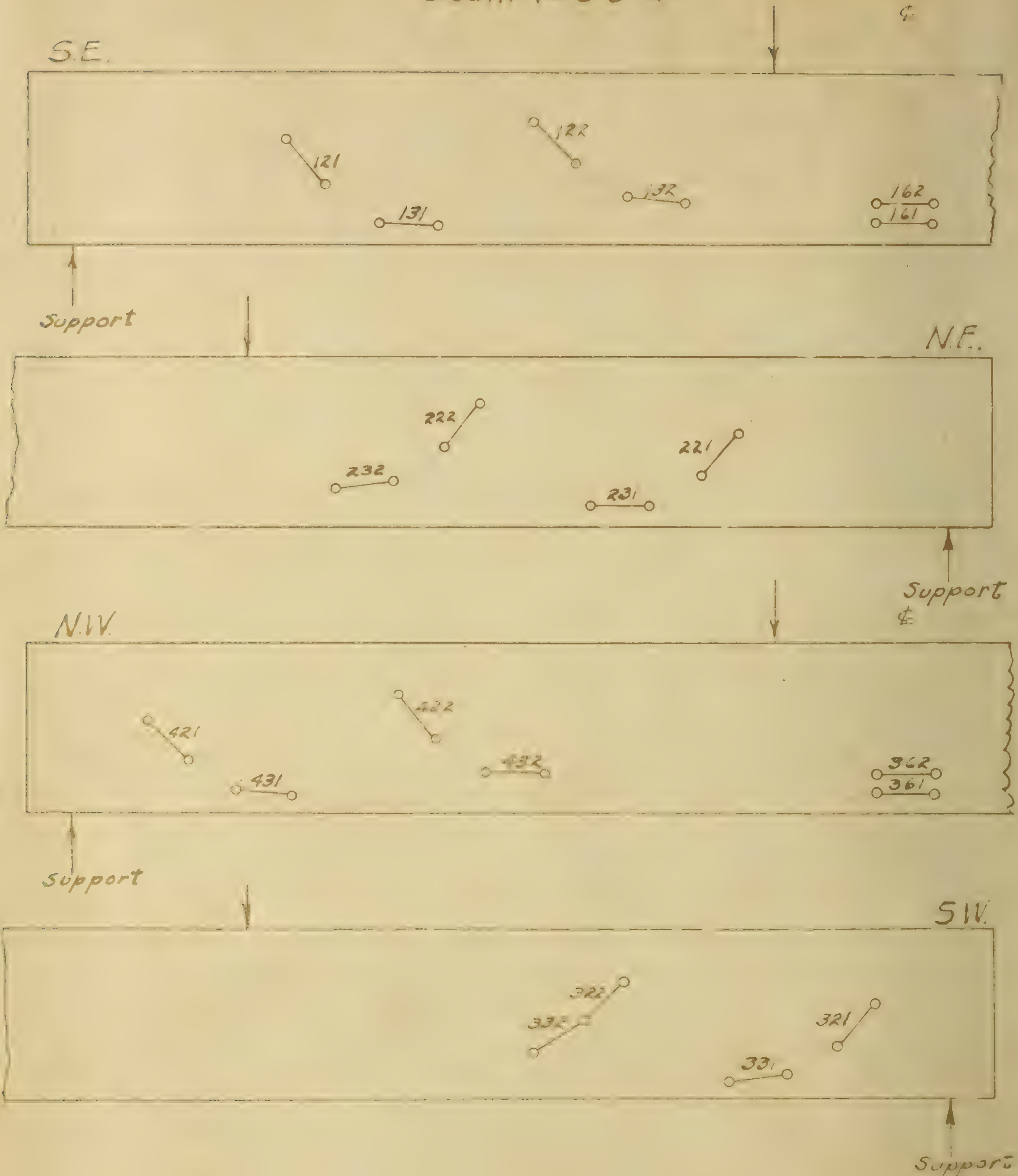


Fig.6a

Beam 16 B3-2

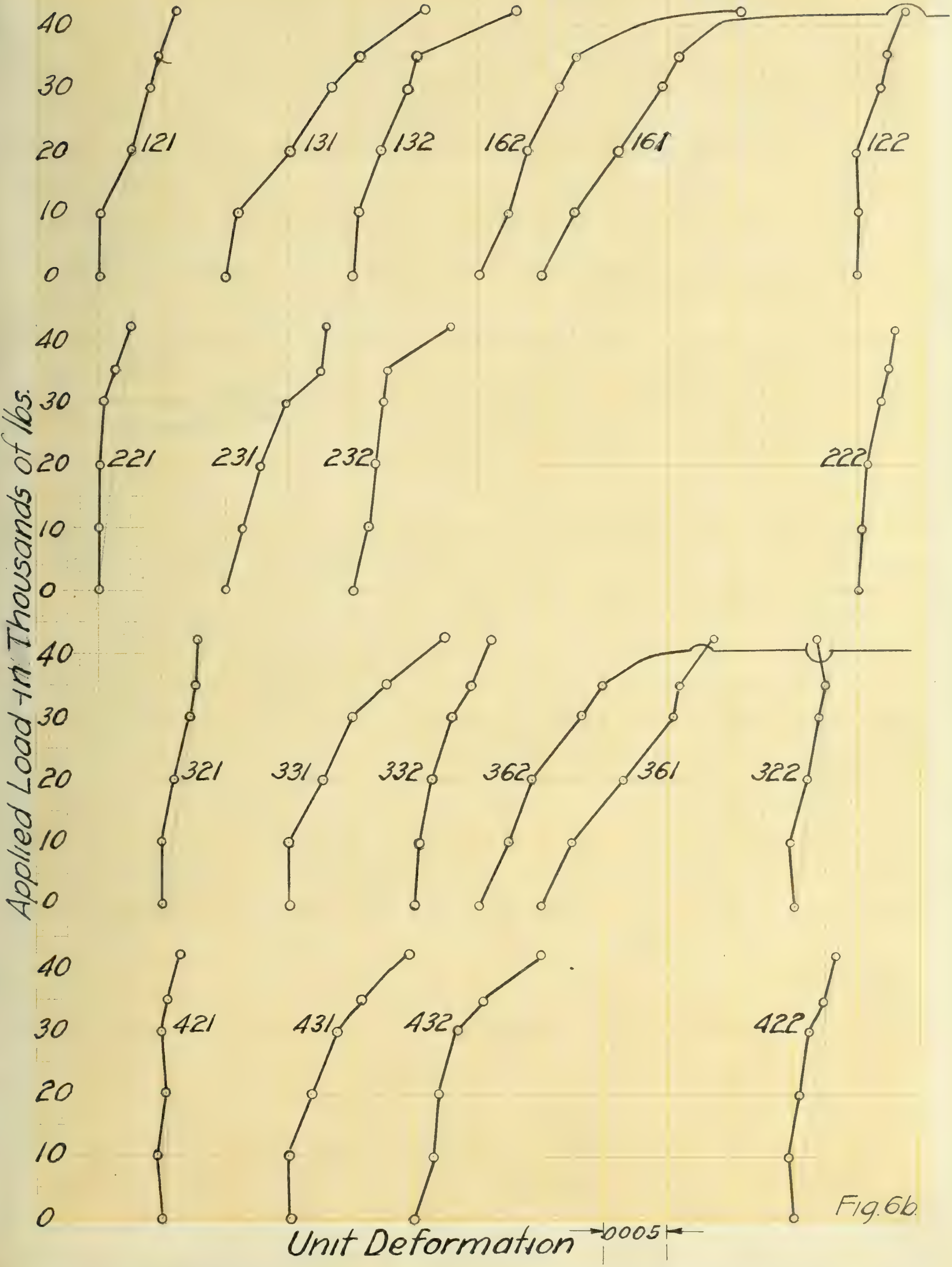


Fig. 6b.

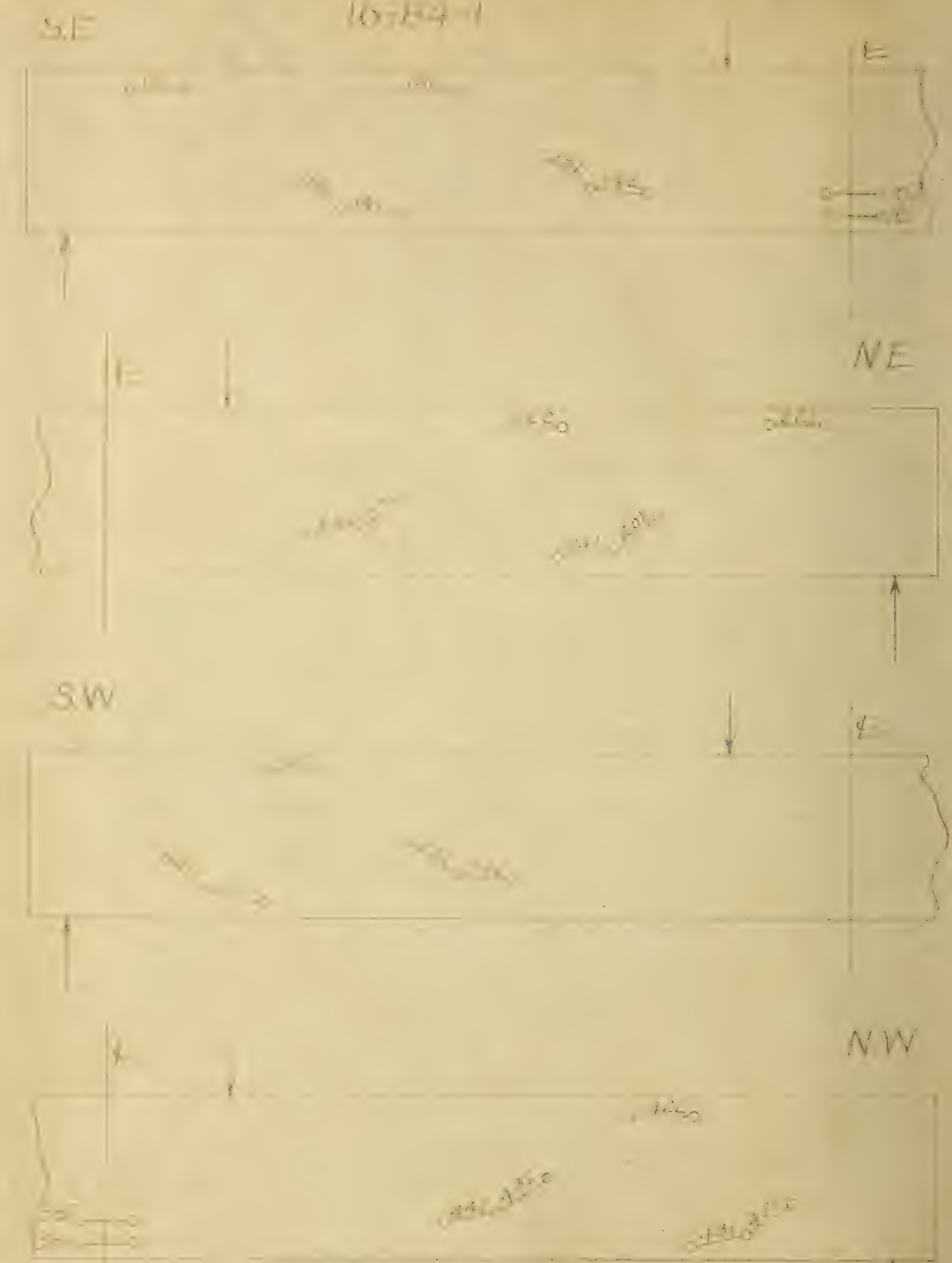


Fig. 7a.

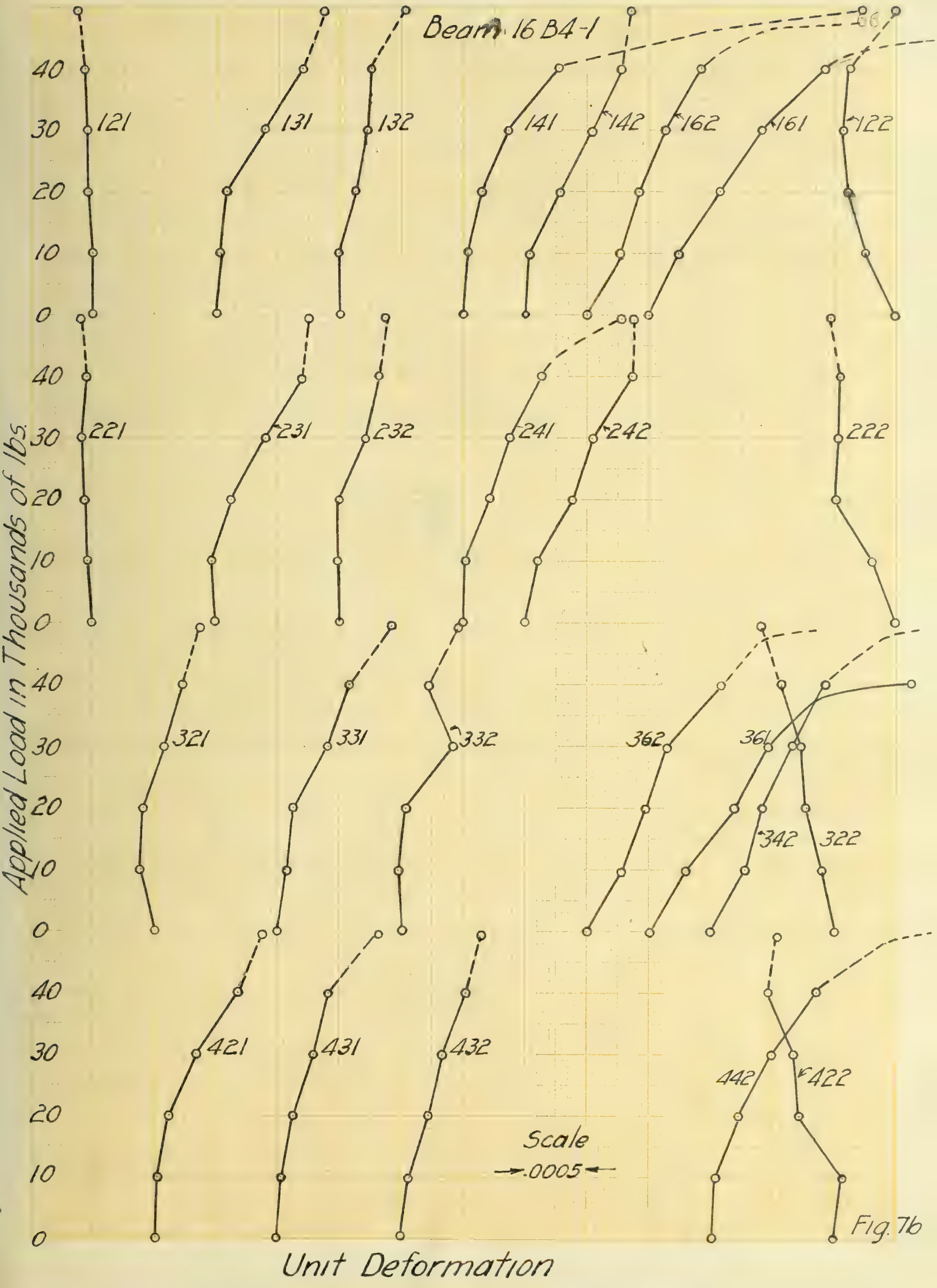

Beam 16 B4-1
Applied Load in Thousands of lbs.
Unit Deformation
0
10
20
30
40
121
131
132
141
142
162
161
122
36
221
231
232
241
242
222
321
331
332
362
361
342
322
421
431
432
442
422
Scale
.0005

Fig. 7b

16-B5-1

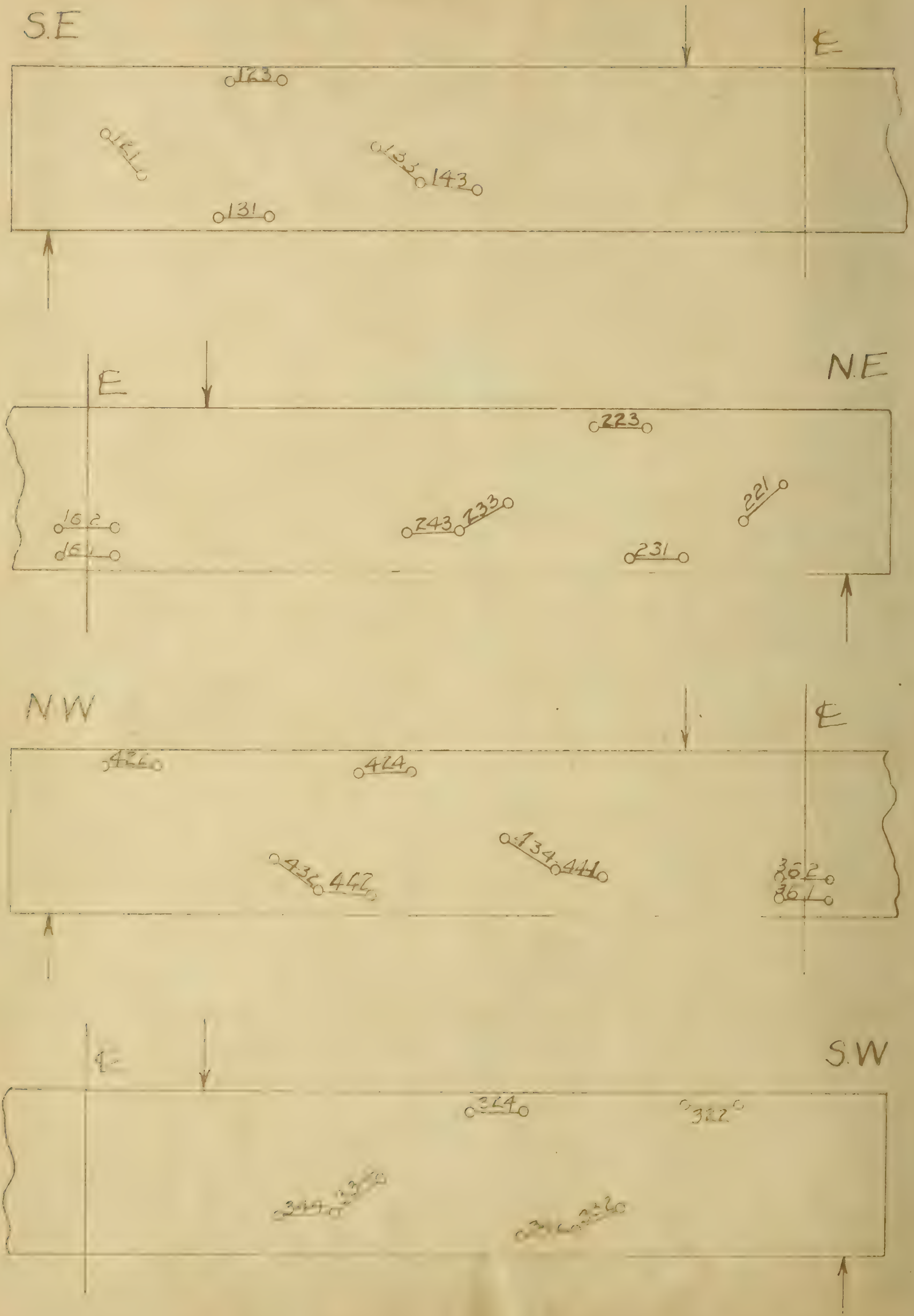

S.E
℄
E
N.E
NW
℄
S.W

Fig. 8a

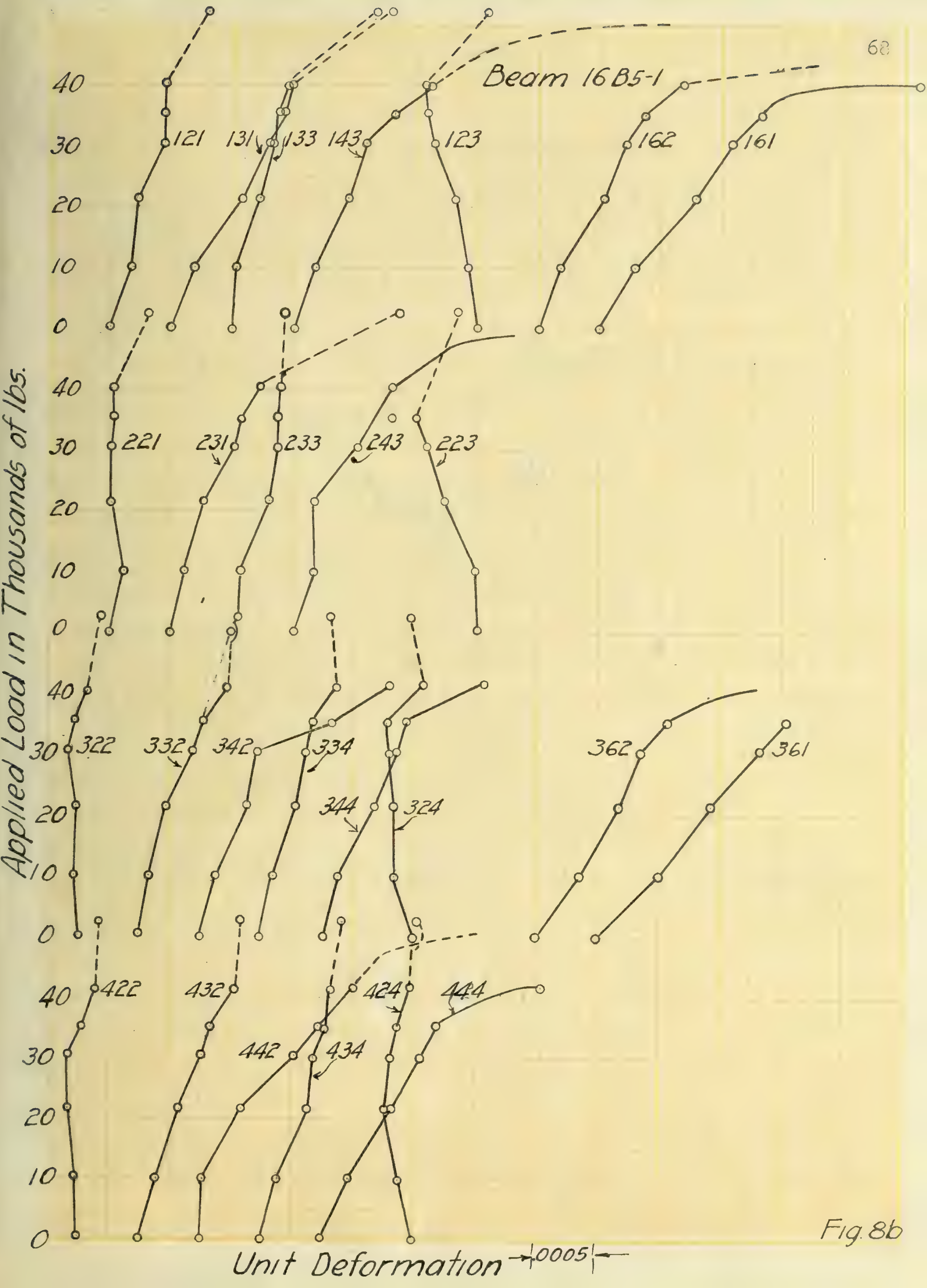
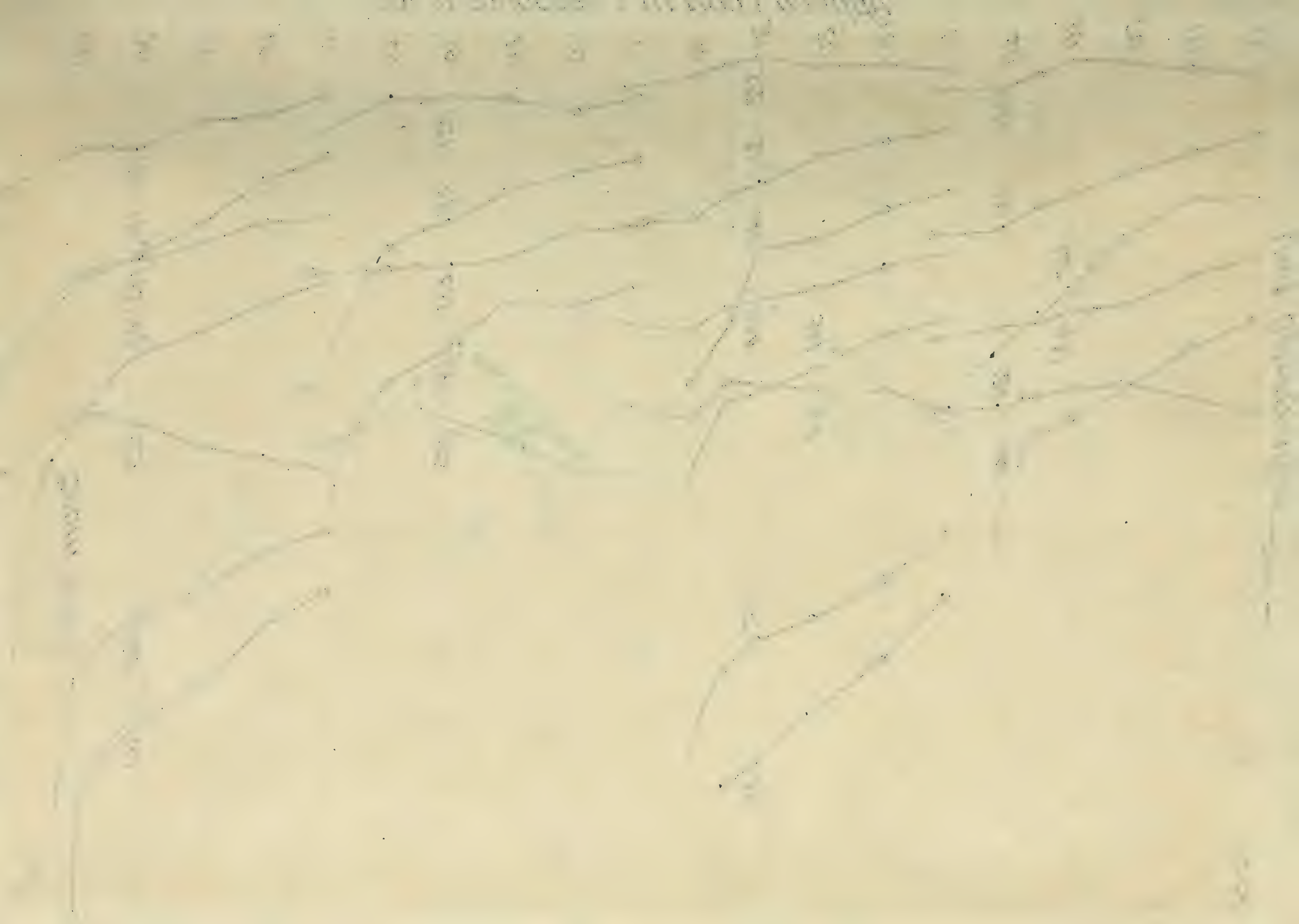

Beam 16 B5-1
121
131
133
143
123
162
161
221
231
233
243
223
322
332
342
334
344
324
362
361
422
432
424
444
442
434
40
30
20
10
0
Applied Load in Thousands of lbs.
Unit Deformation →|.0005|←

Fig. 8b



16-B6-1

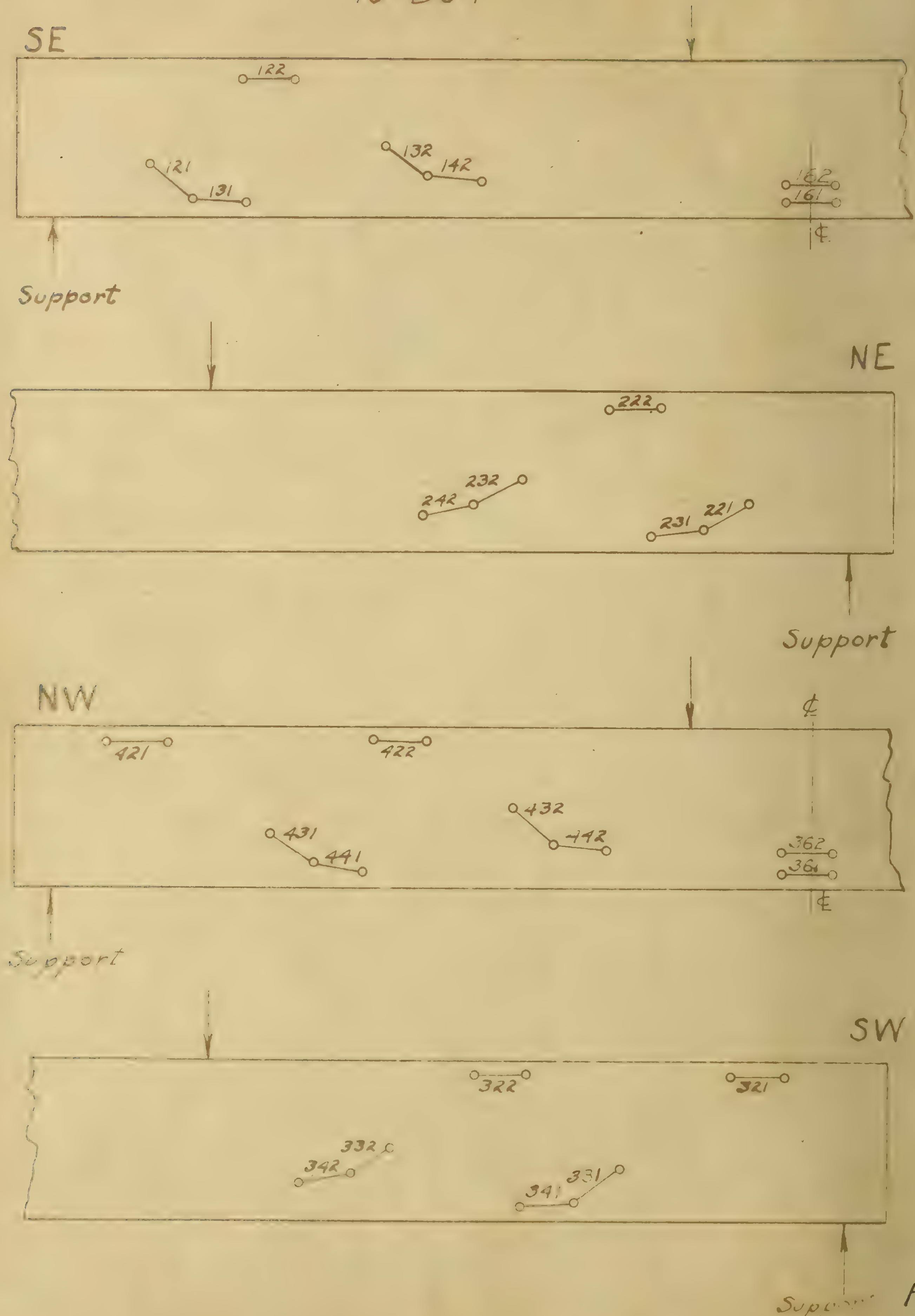

SE
℄
Support
NE
Support
NW
℄
℄
Support
SW
Support

Fig.9

Beam 16 B6-1

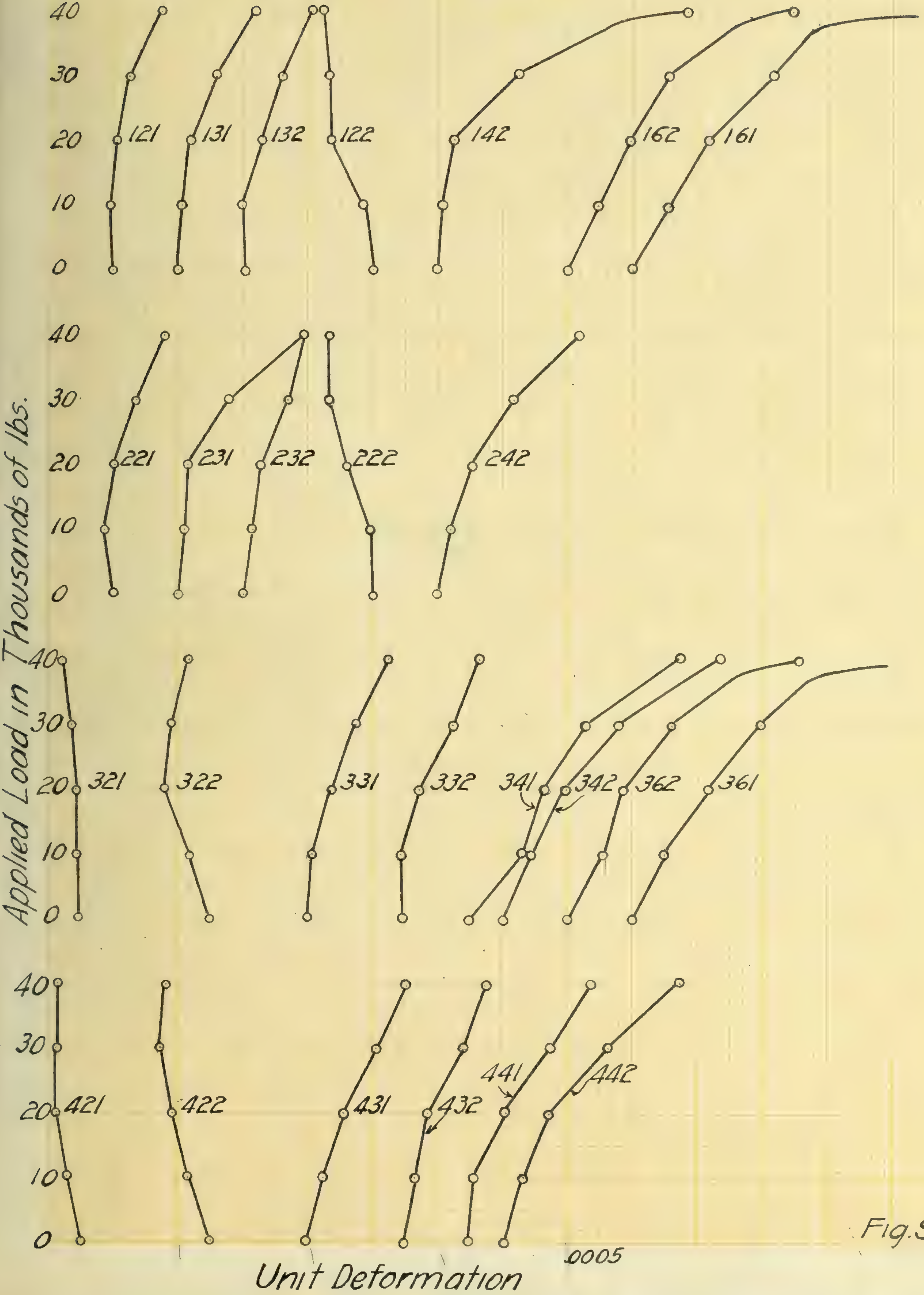


Fig. 9b.

16 - B 7-1

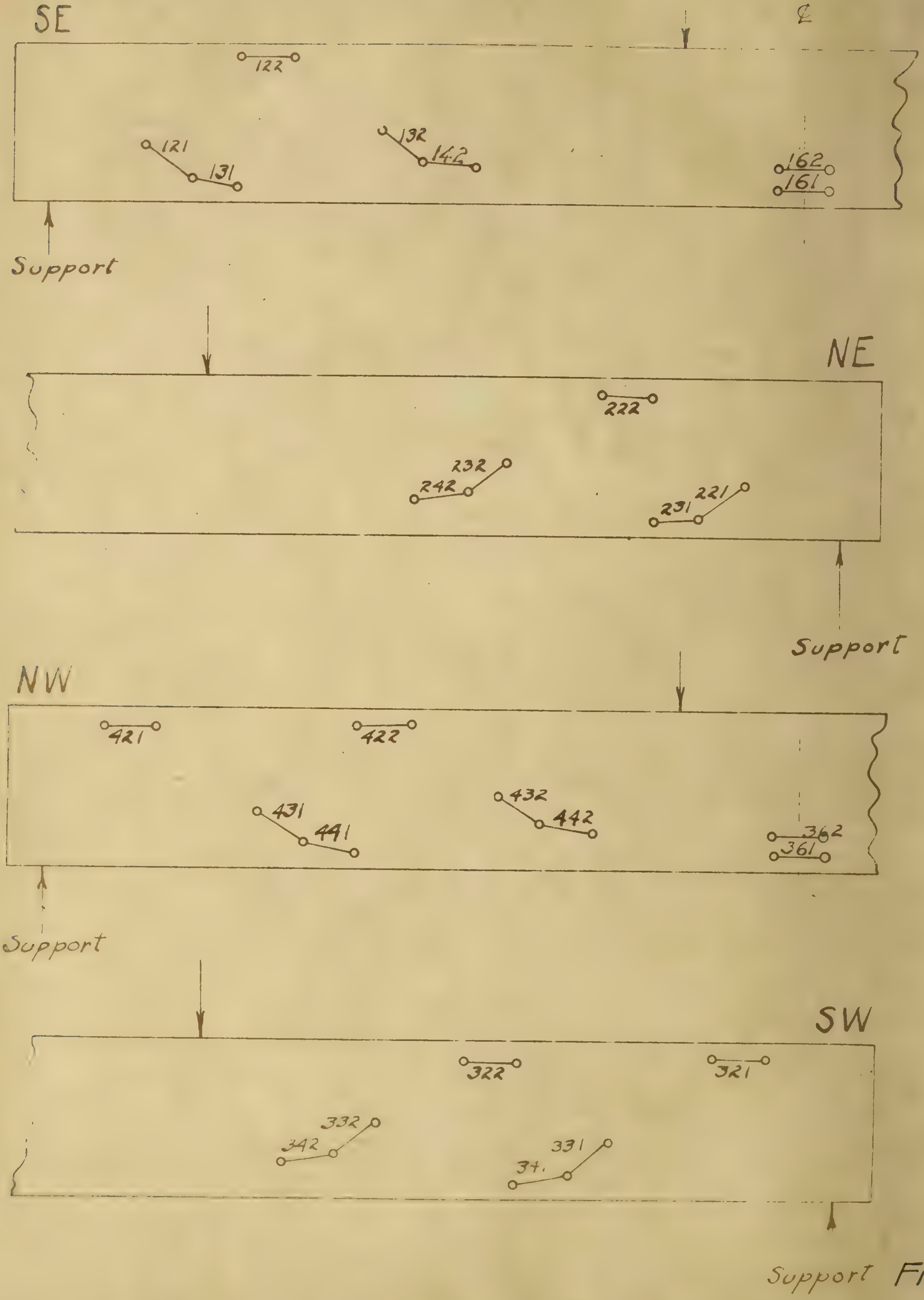

SE
℄
Support
NE
Support
NW
Support
SW
Support

Fig.10

Beam 16 B7-1.

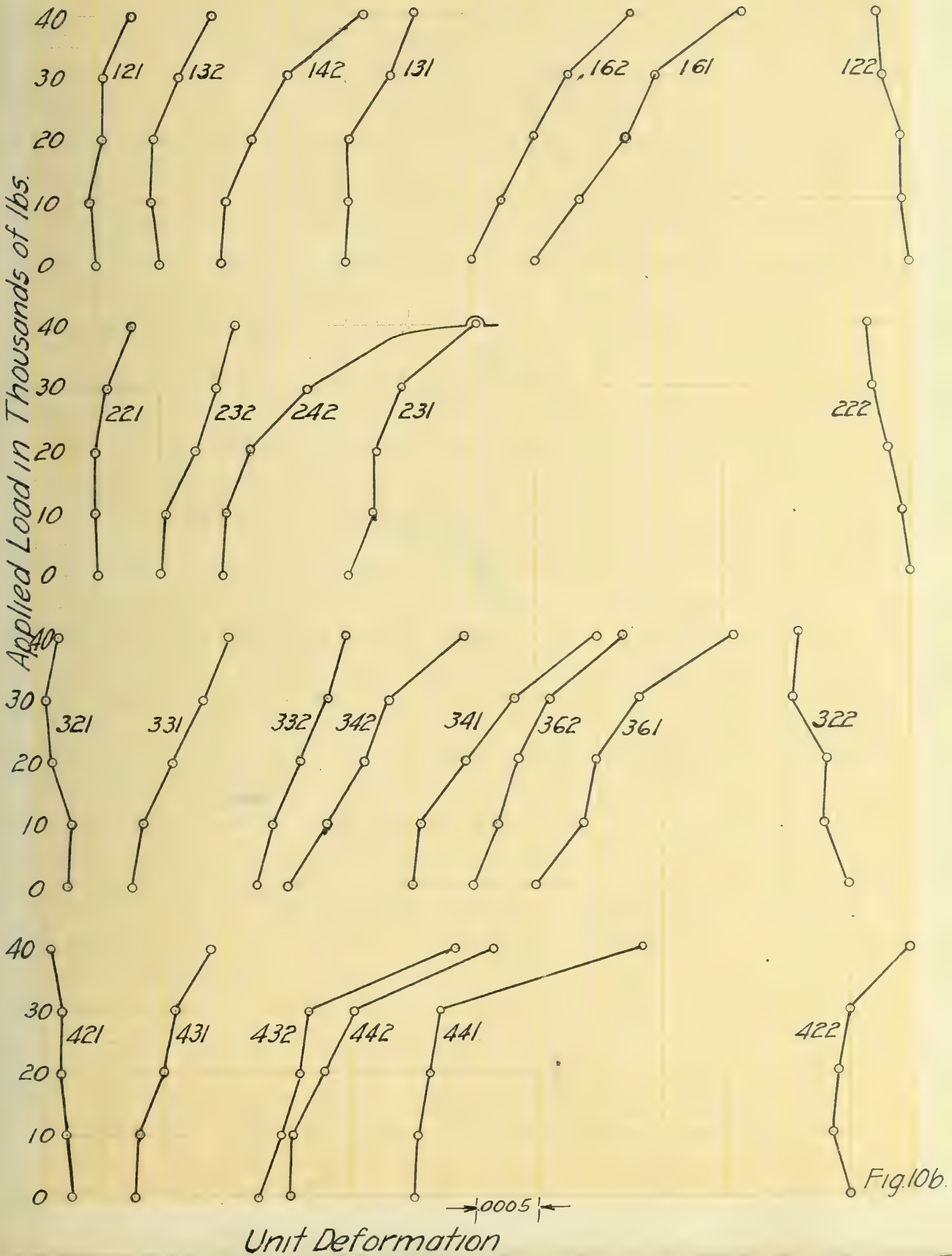


Fig. 10b.

Beam 16 58-1

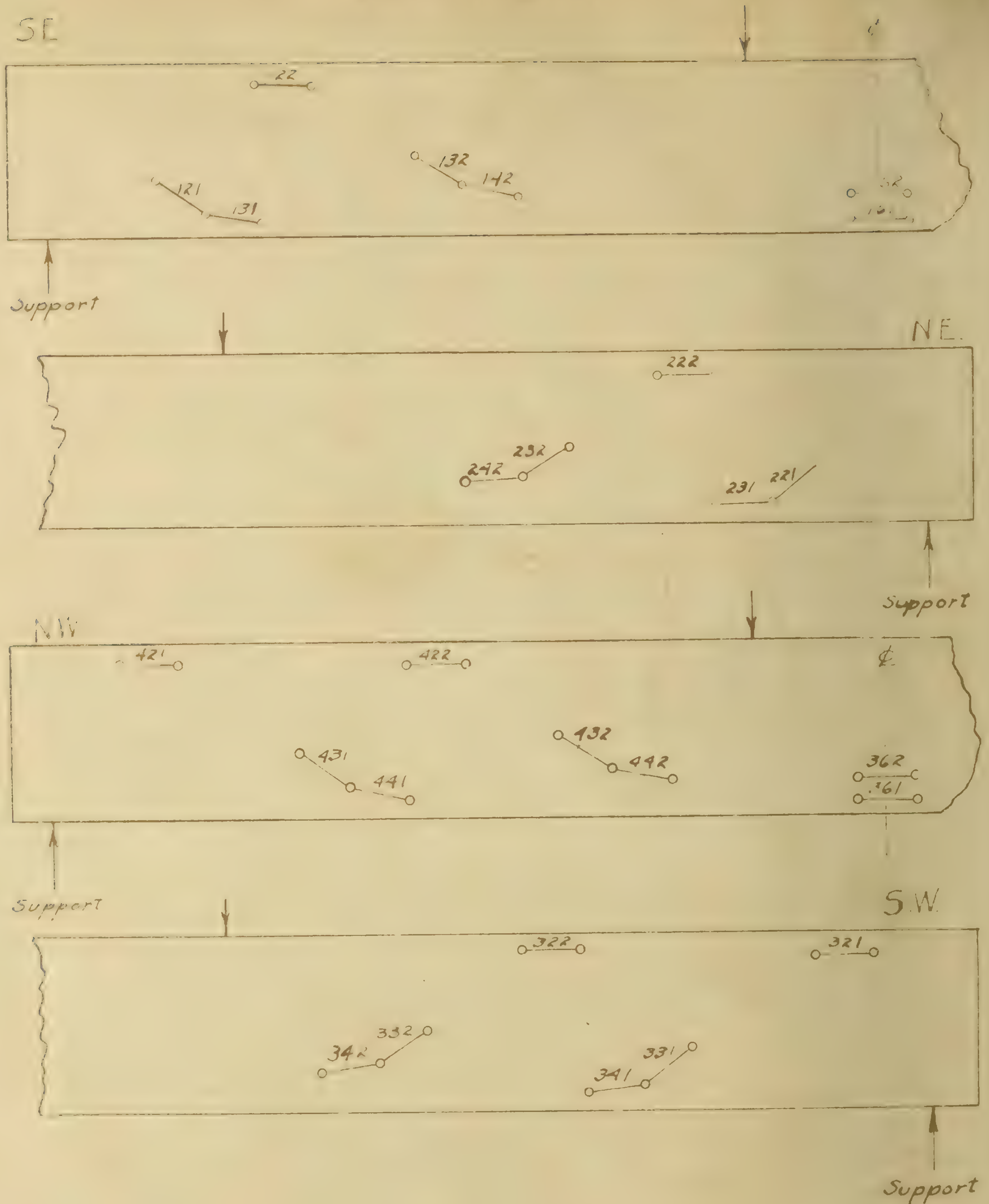


Fig. 11a.

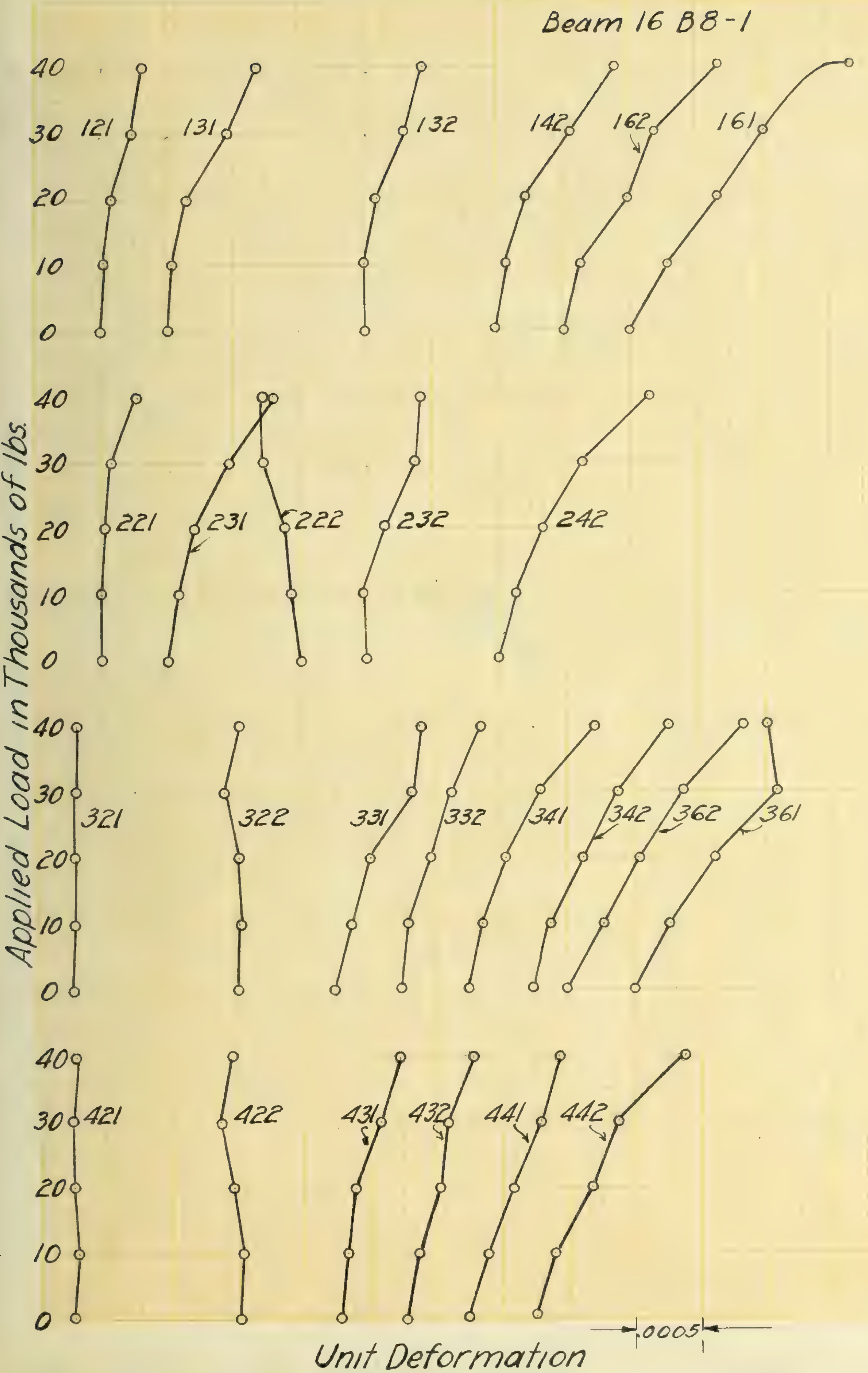

Beam 16 B8-1
Applied Load in Thousands of lbs.
40
30
20
10
0
121
131
132
142
162
161
221
231
222
232
242
321
322
331
332
341
342
362
361
421
422
431
432
441
442
.0005
Unit Deformation

Fig. 11b.

Beam 16B9-1

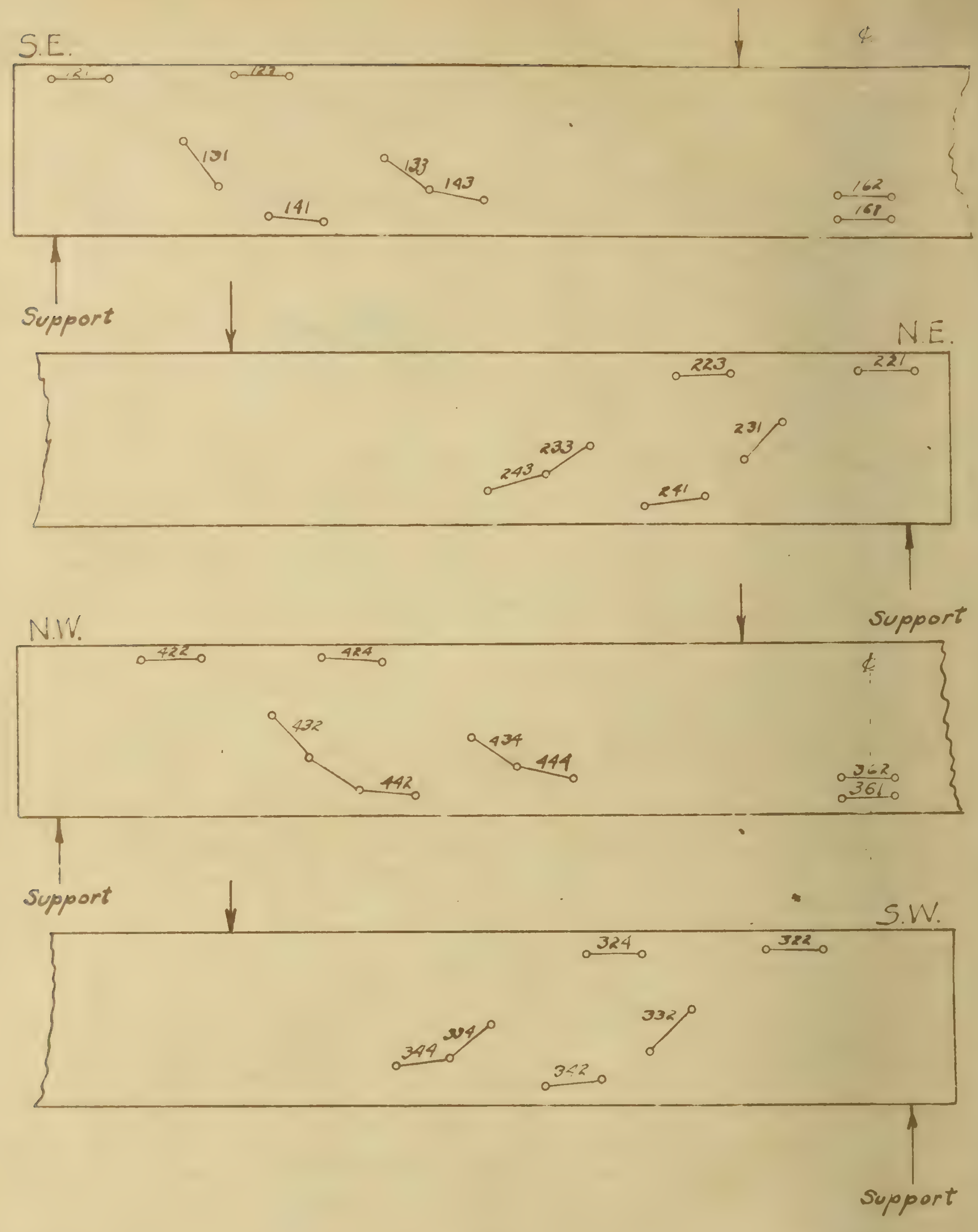


Fig.12

Beam 16 B9-1

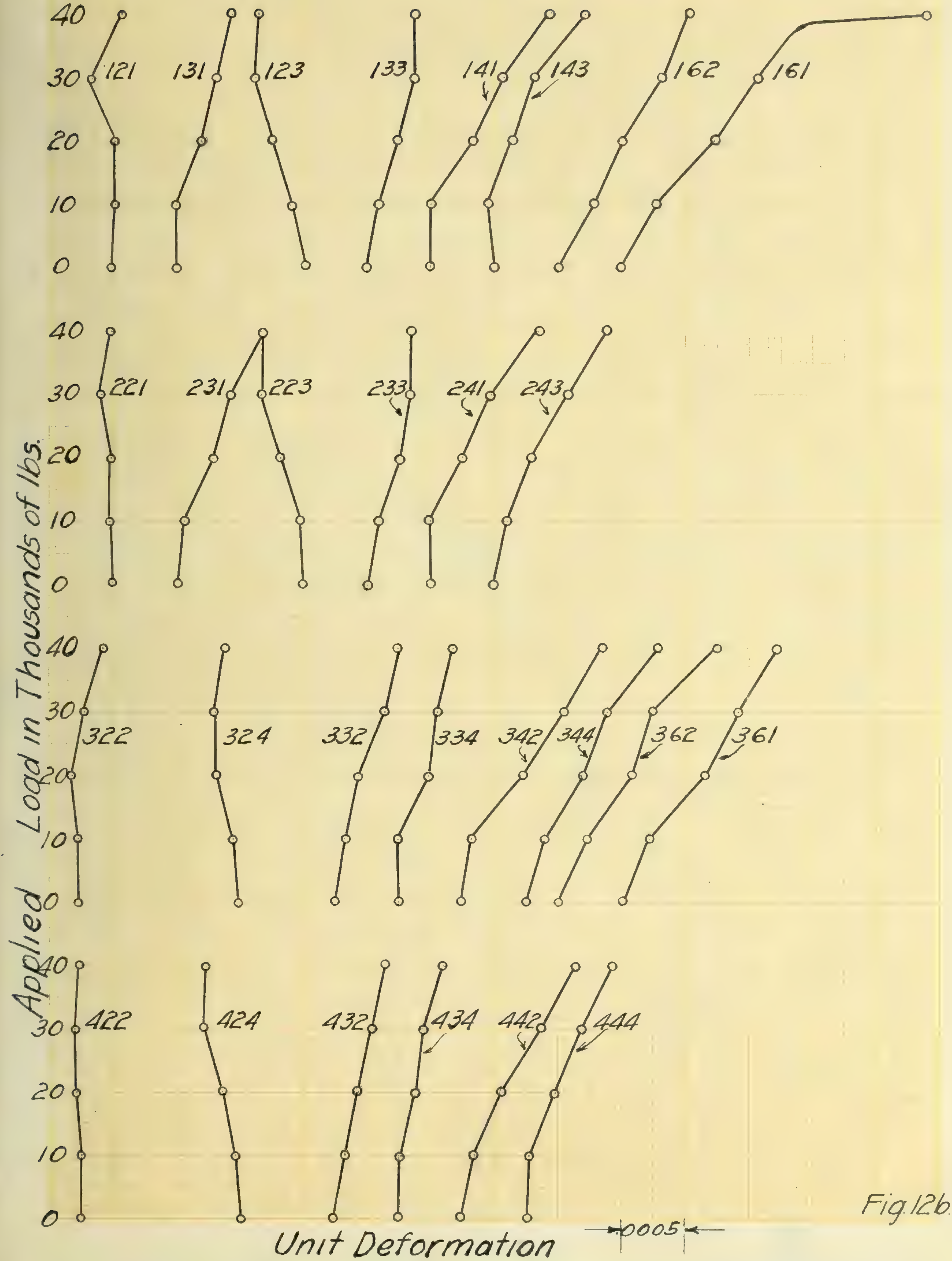


Fig.12b.

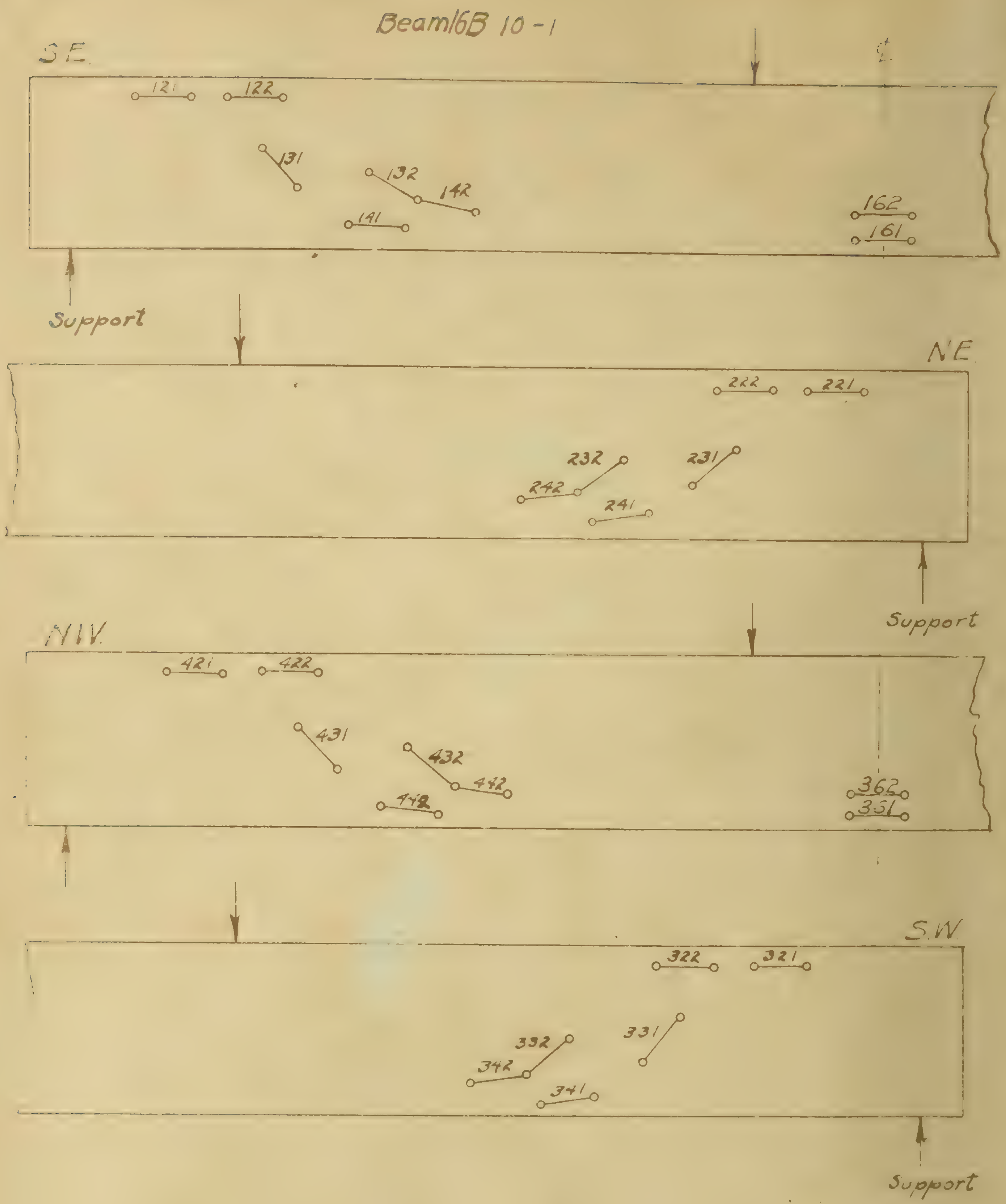

Beam16B 10-1
S.E.
℄
Support
N.E.
Support
N.W.
S.W.
Support

Fig. 13a

Beam 16 B10-1

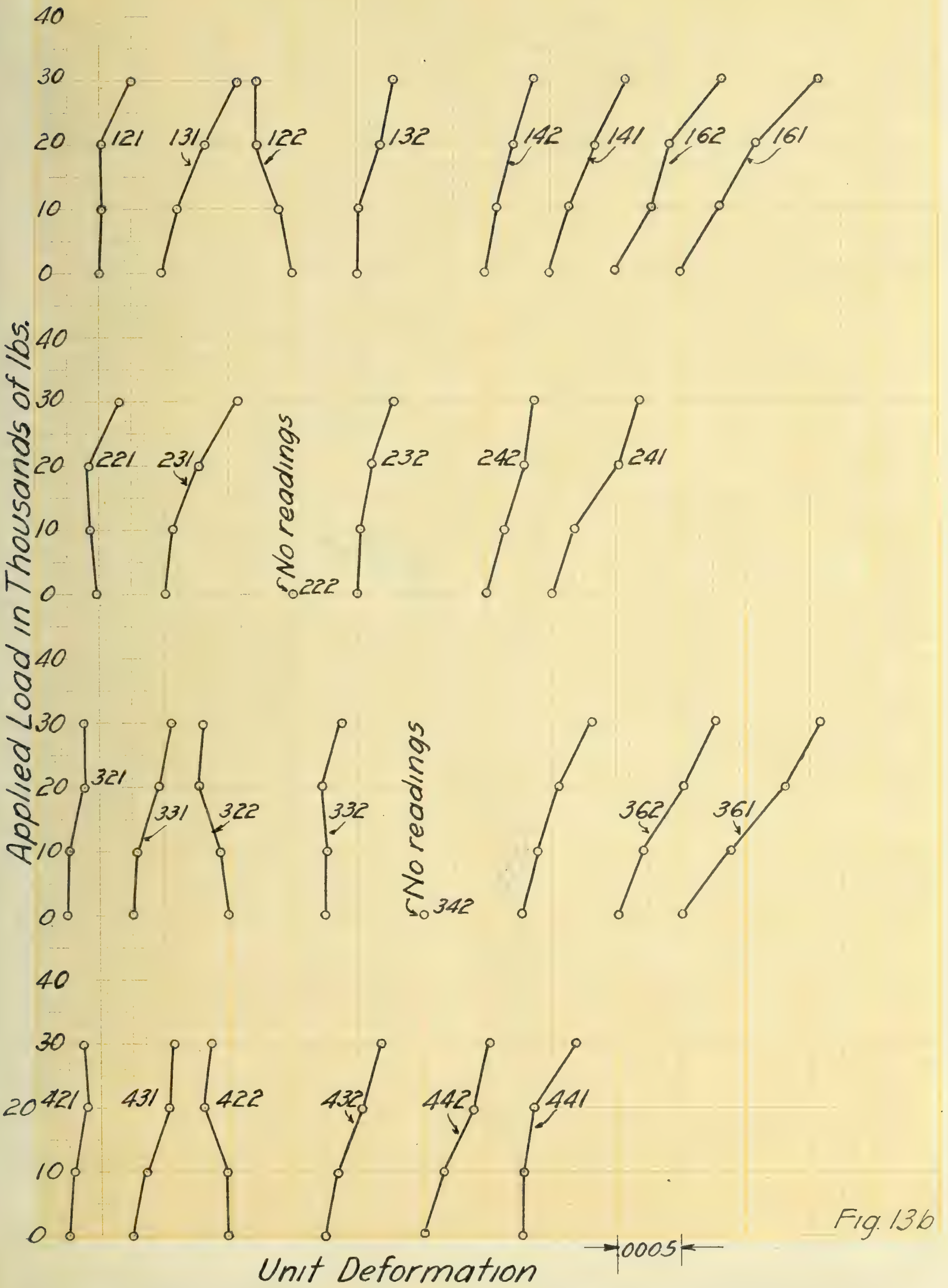


Fig. 13b

Beam 16-B11-1

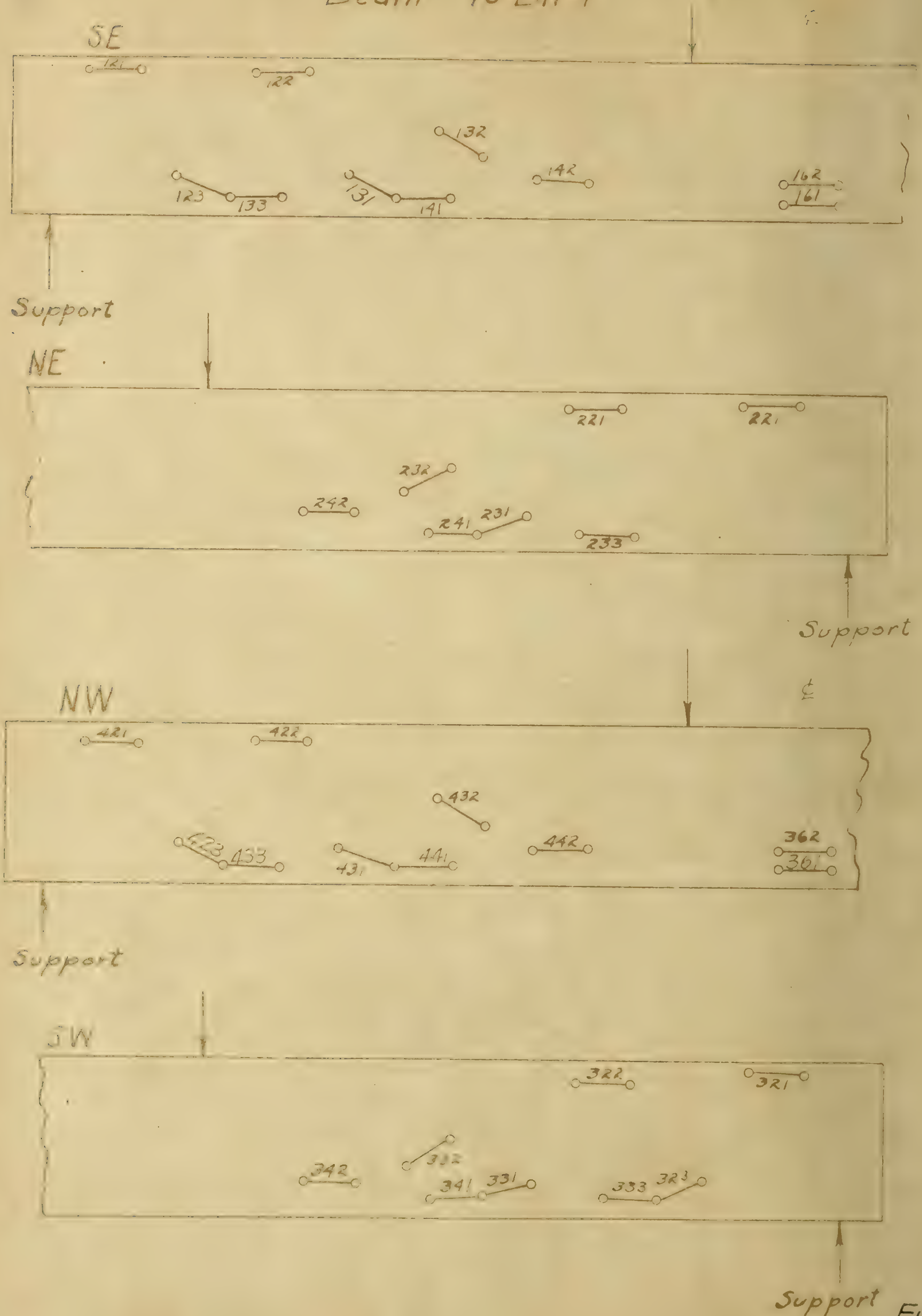


Fig.14a

Beam 16 B11-1

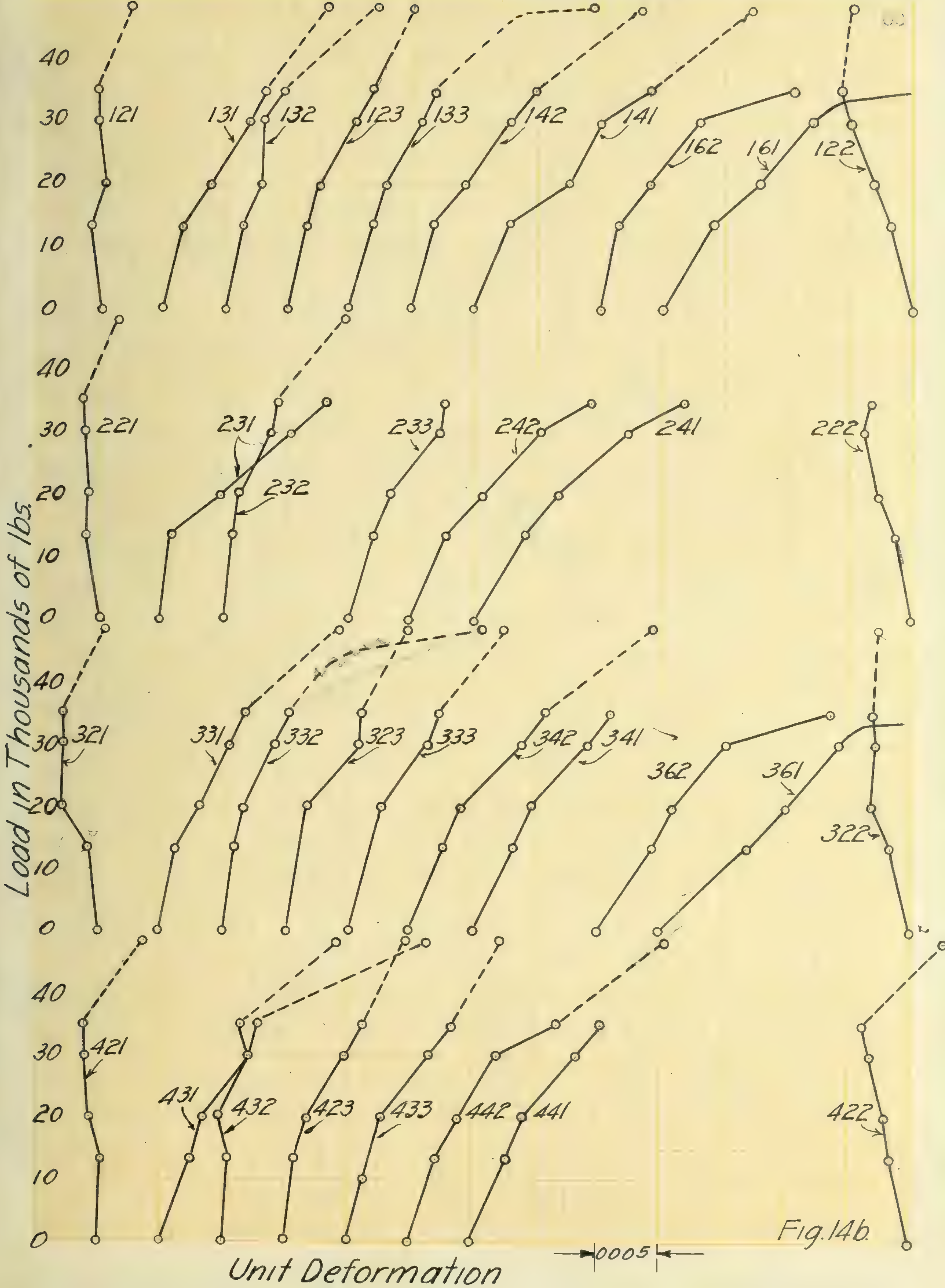


Fig. 14b.

Beam 16B 12-1

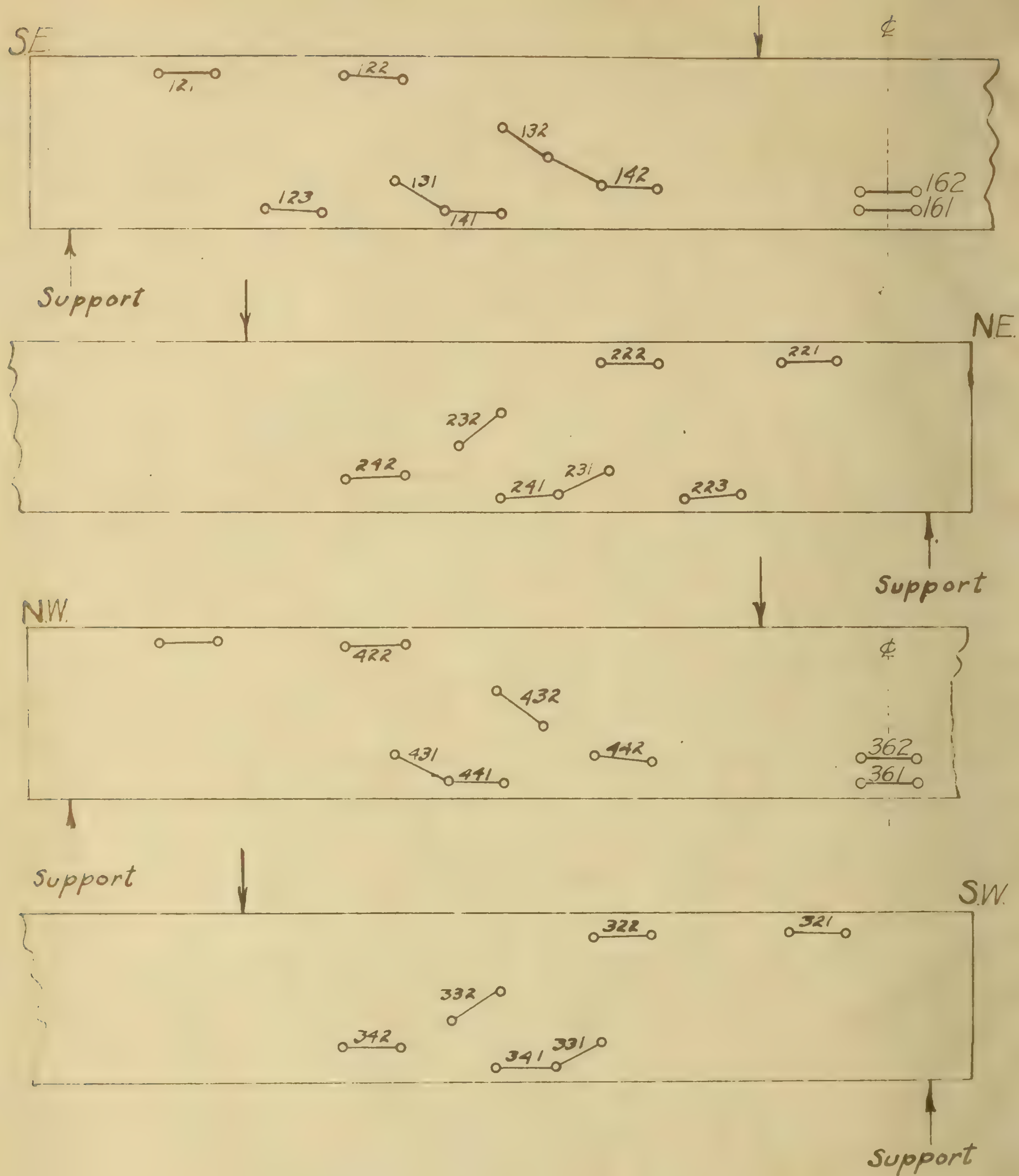


Fig.15a

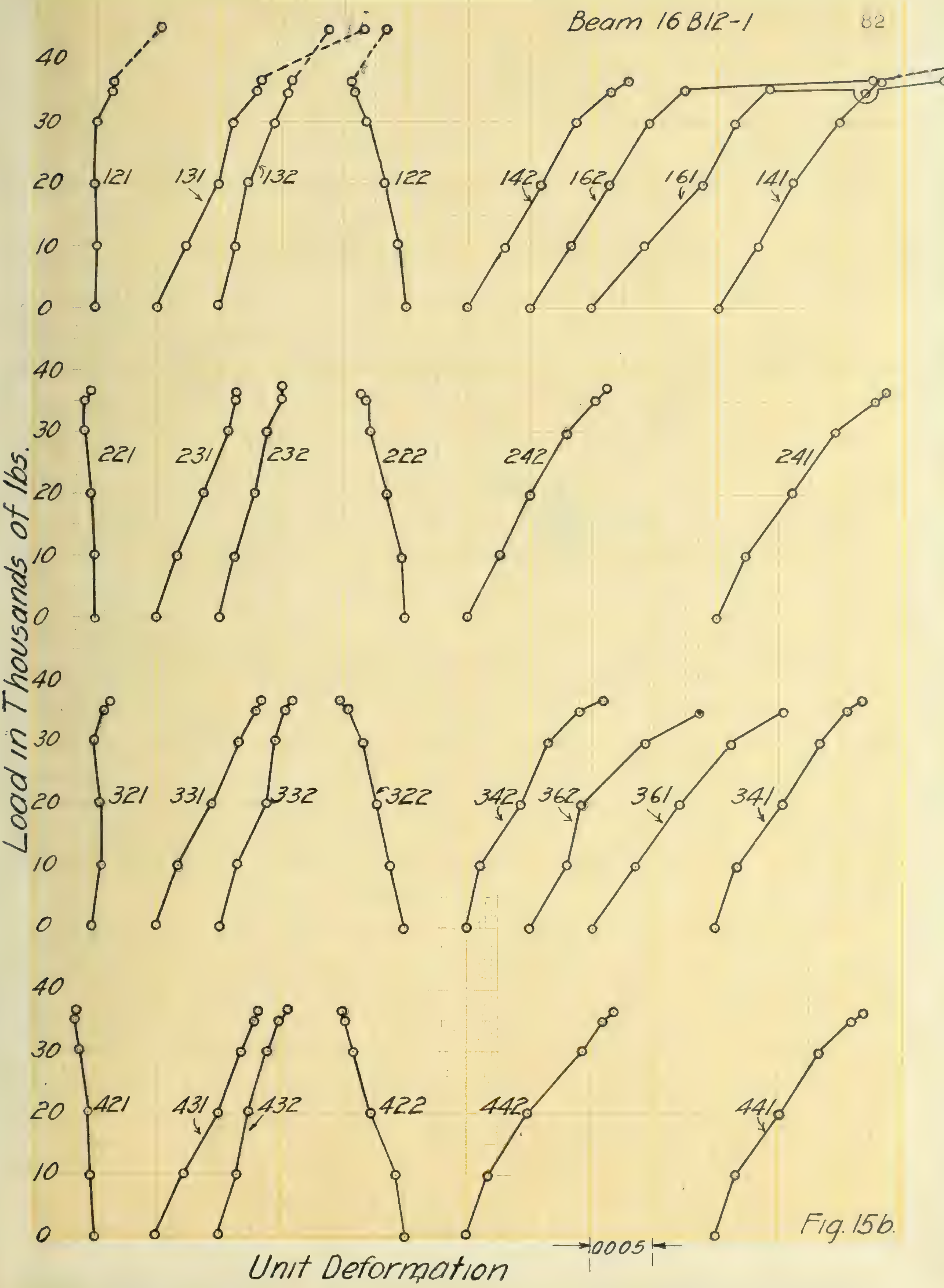

Beam 16 B12-1
Load in Thousands of lbs.
Unit Deformation
.0005
0
10
20
30
40
121
131
132
122
142
162
161
141
221
231
232
222
242
241
321
331
332
322
342
362
361
341
421
431
432
422
442
441

Fig. 15b.

16-B13·1

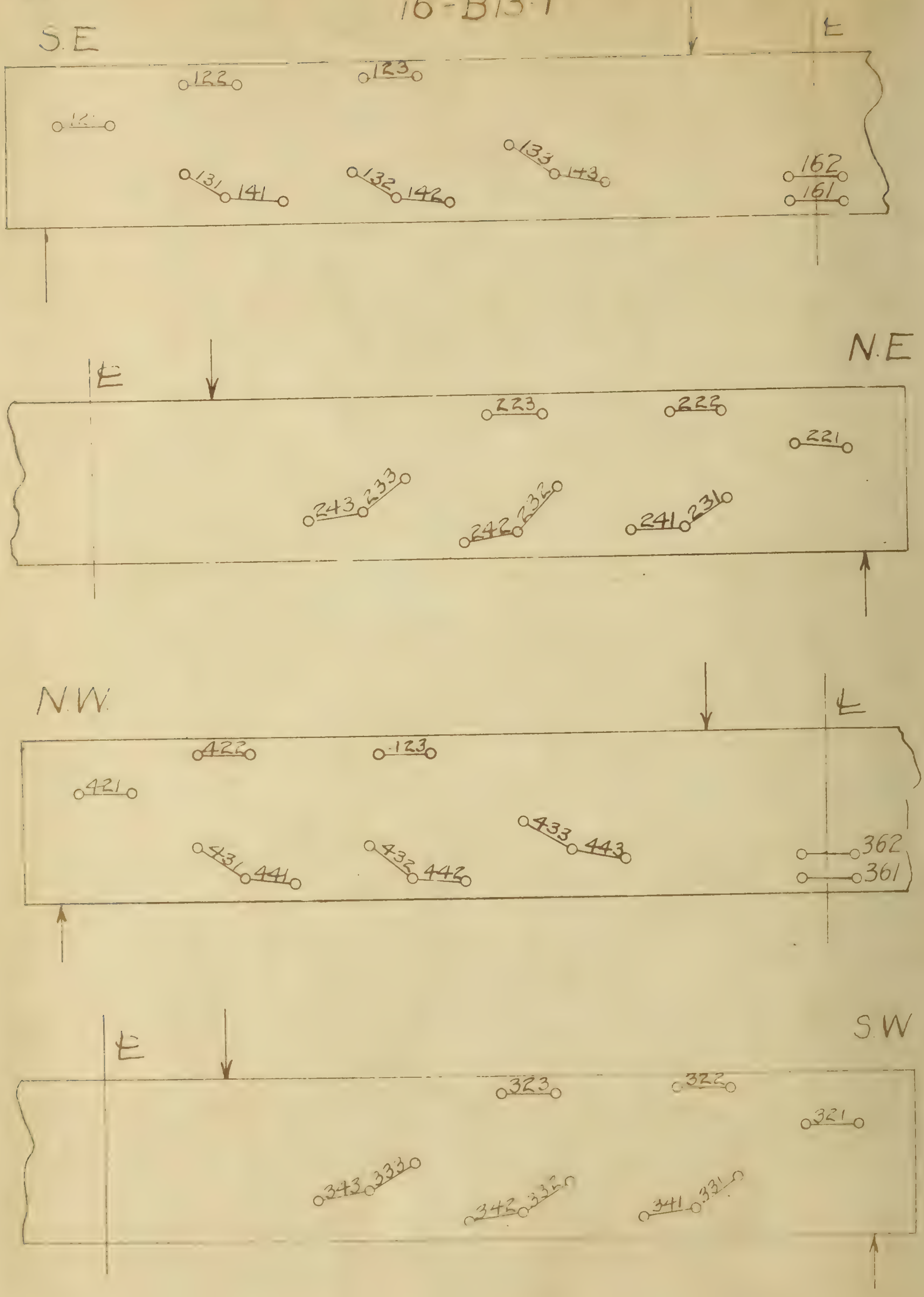


Fig. 16a

Beam 16 B 13-1

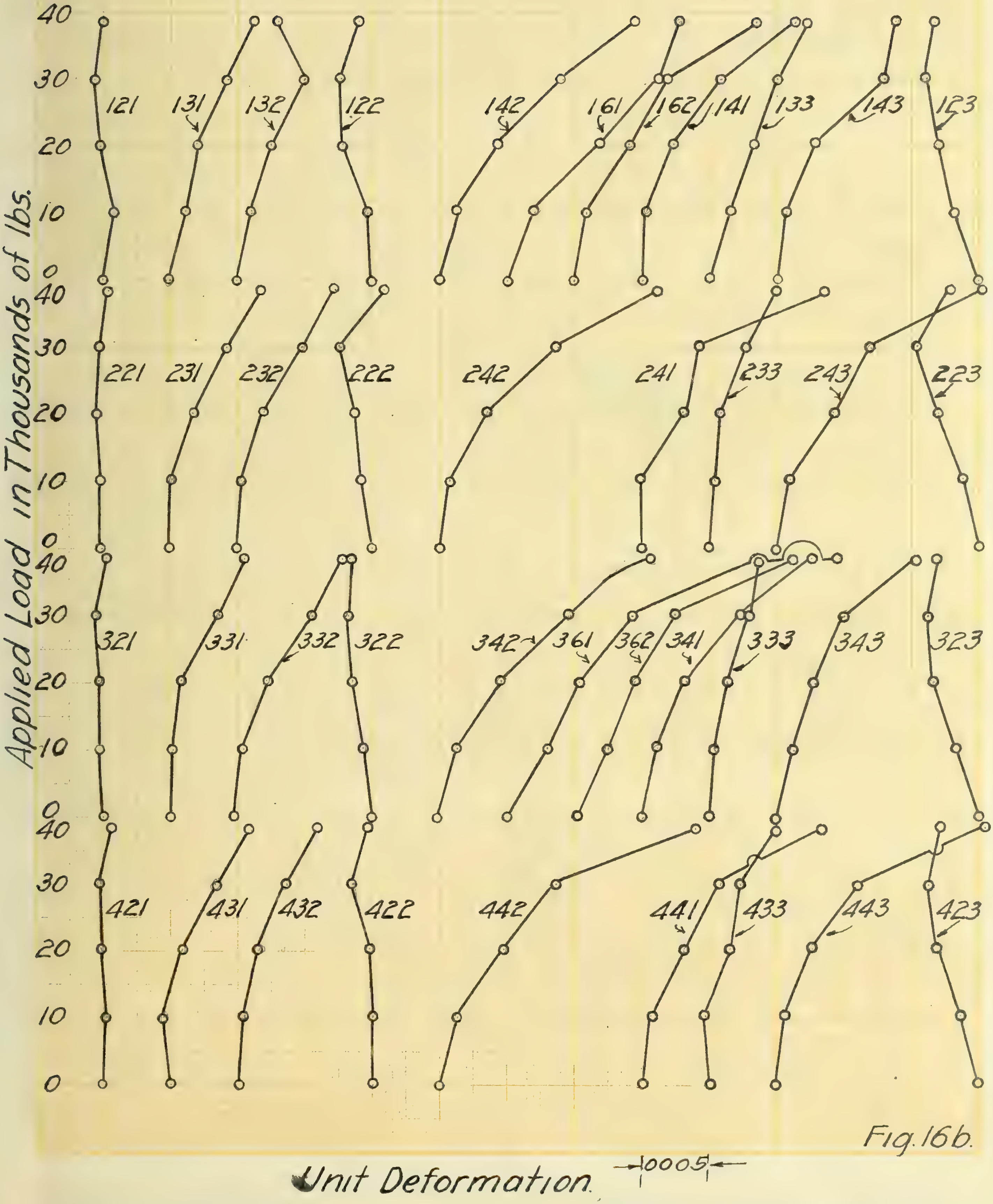
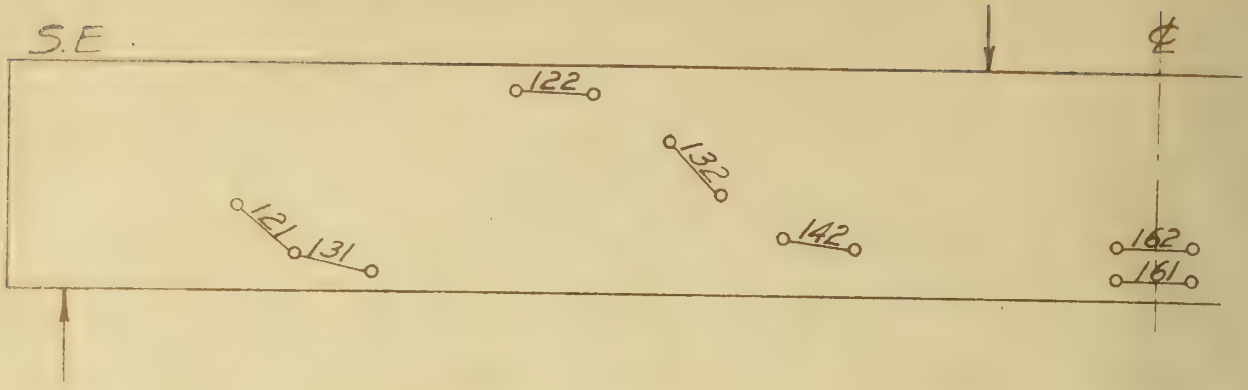
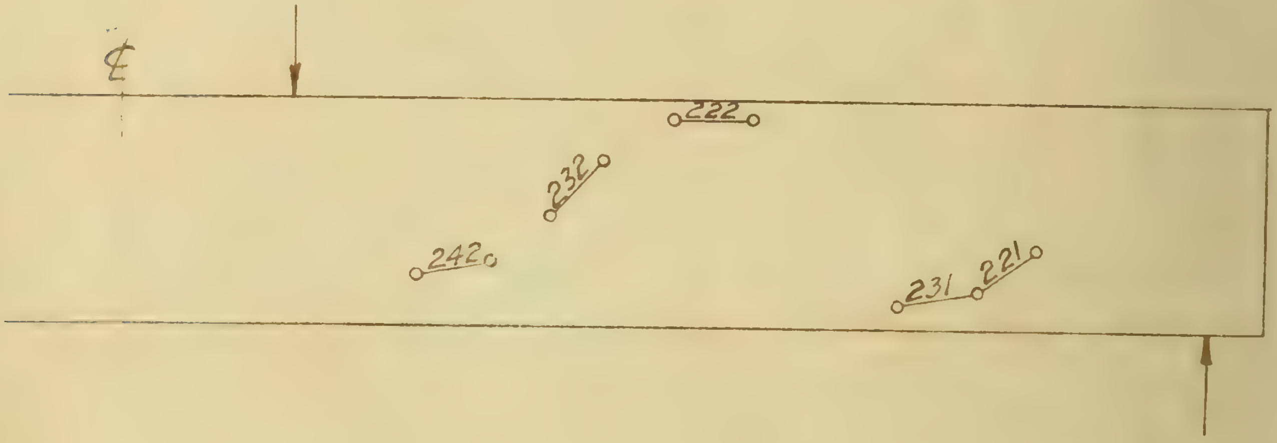
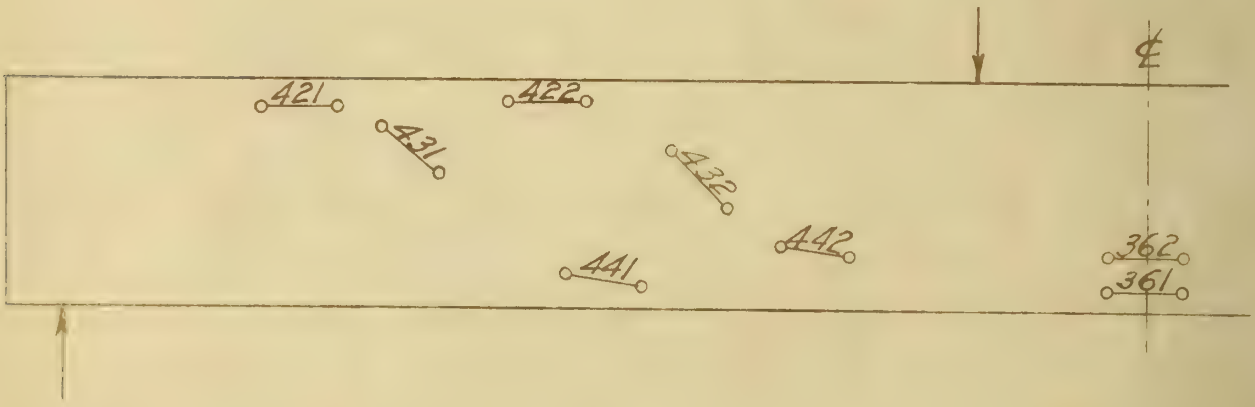


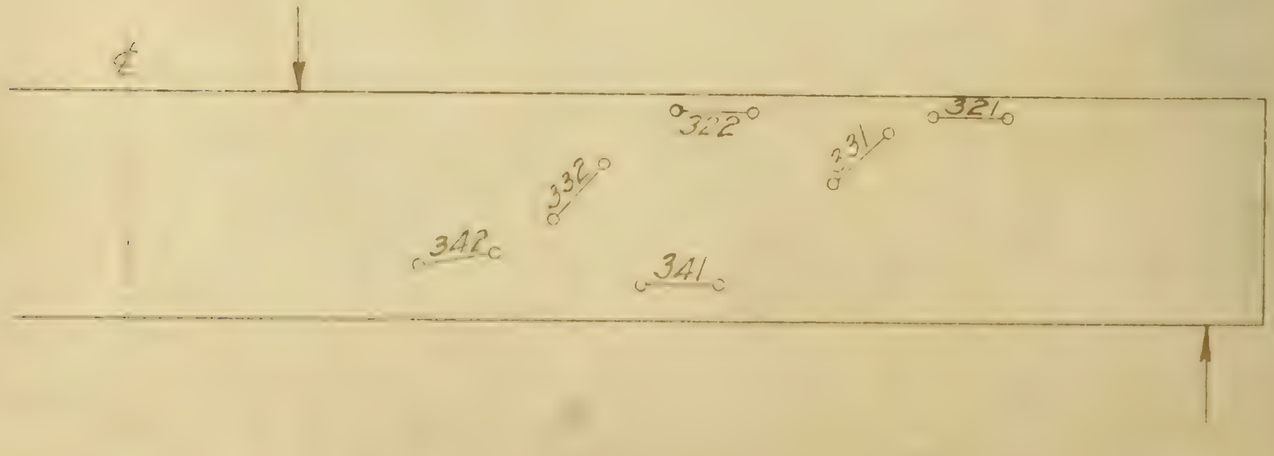
Fig. 16b.

Beam 16 B13-2


S.E
℄


℄


℄


℄

Beam 16 B13-2

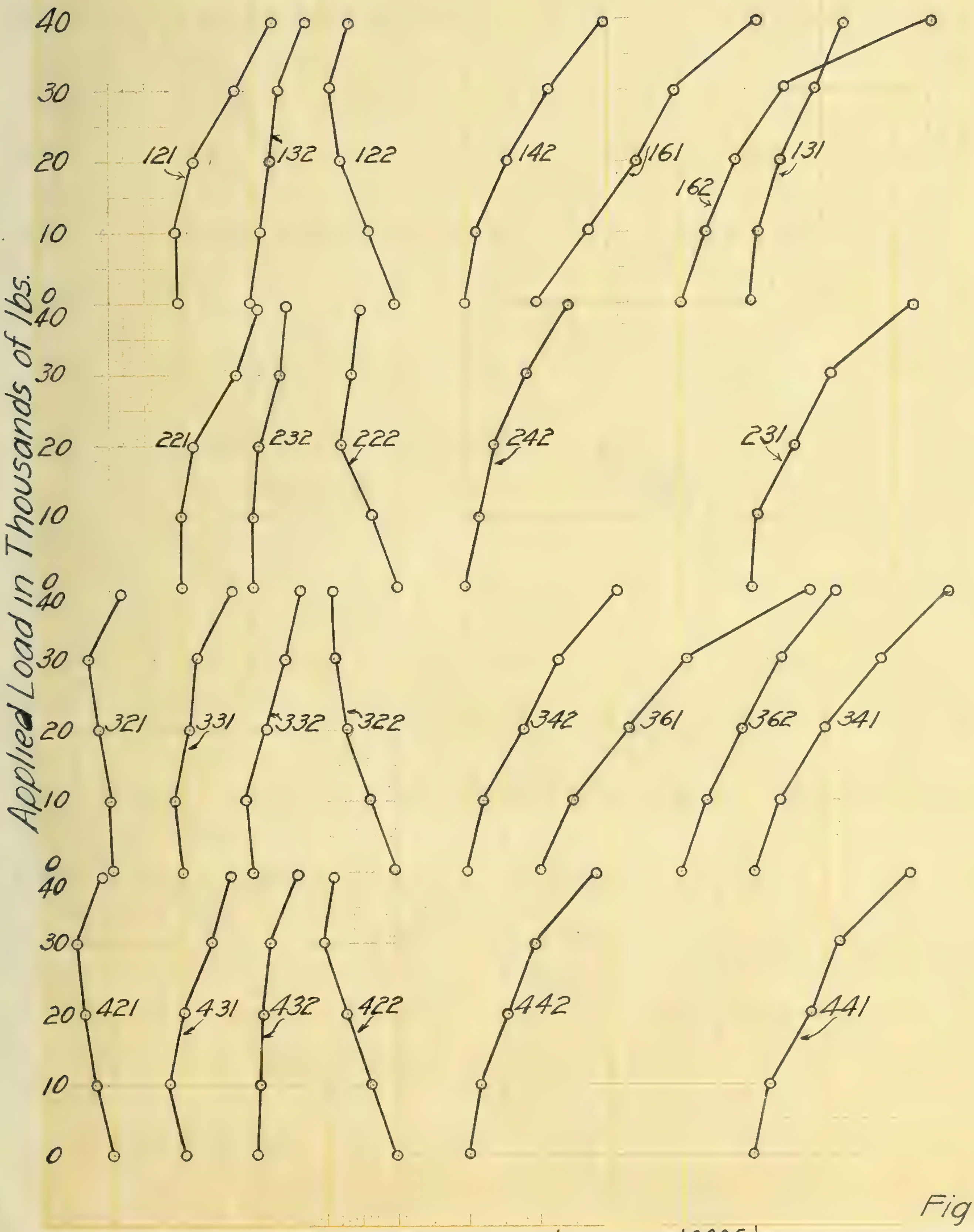


Fig. 17b.

16-B14-1

4-25-17

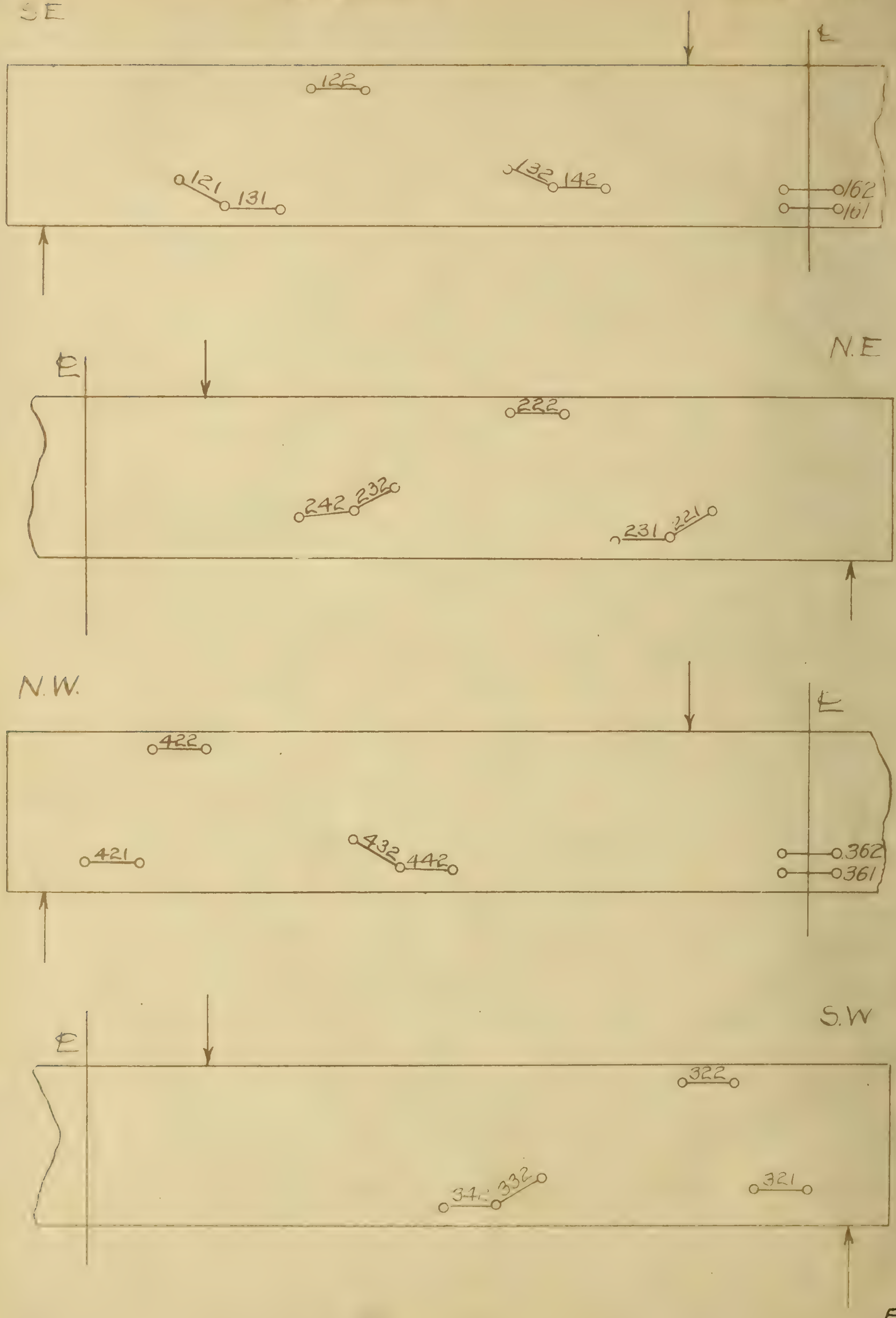


Fig. 18 a.

Beam 16 B14-1

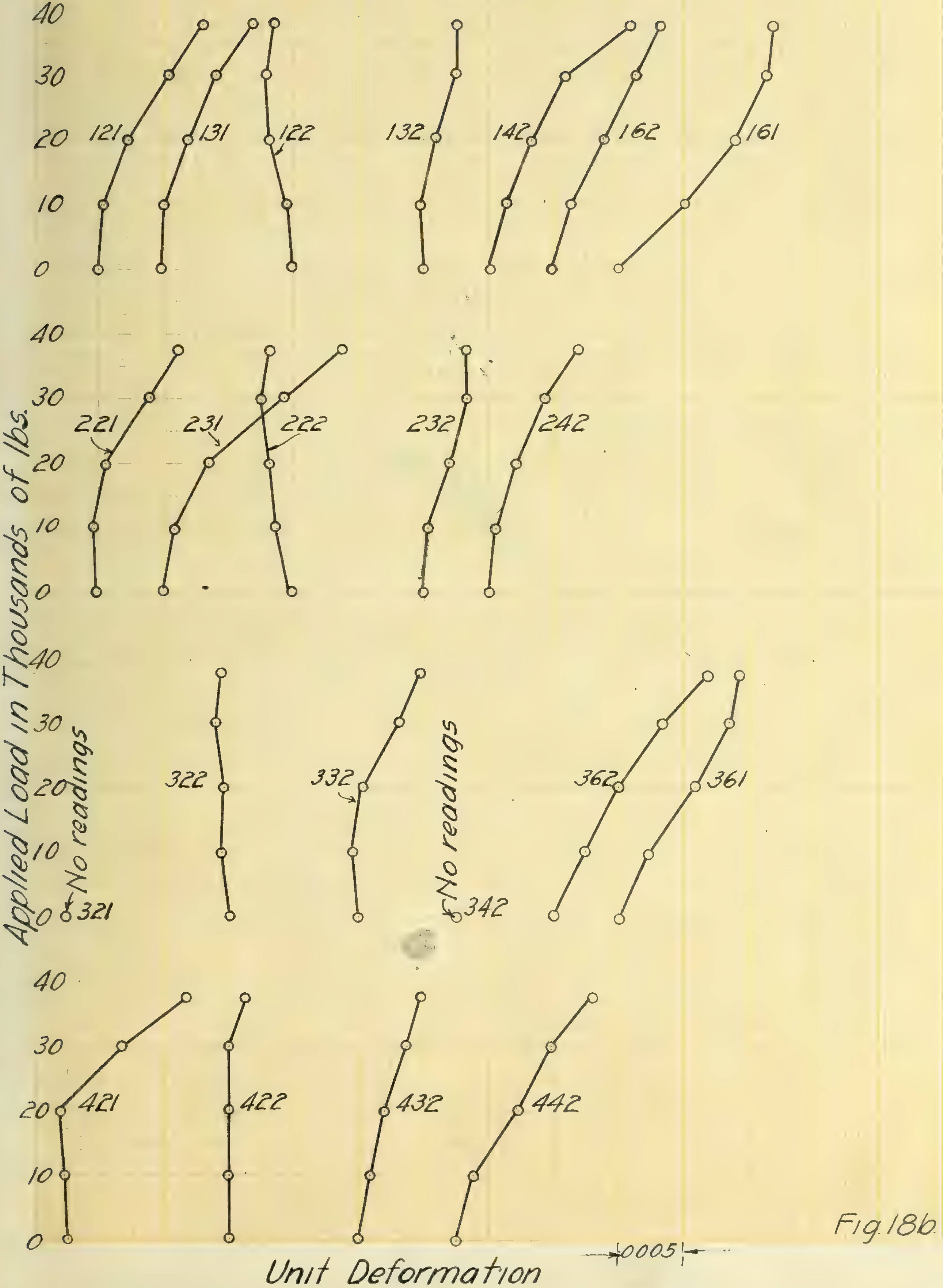


Fig. 18b.

16-B15-1   4-14 17

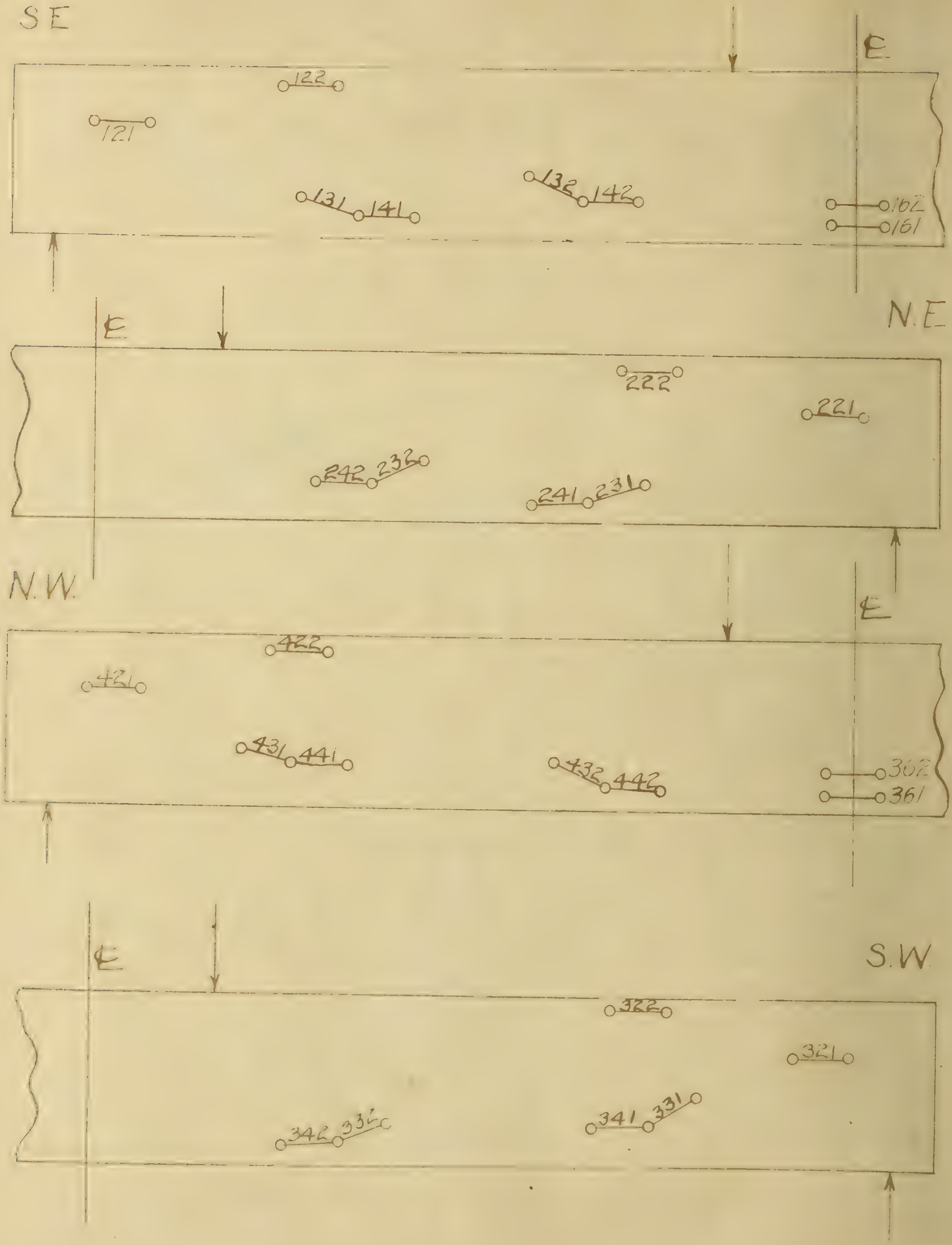


Fig. 19a.

Beam 16 B15-1

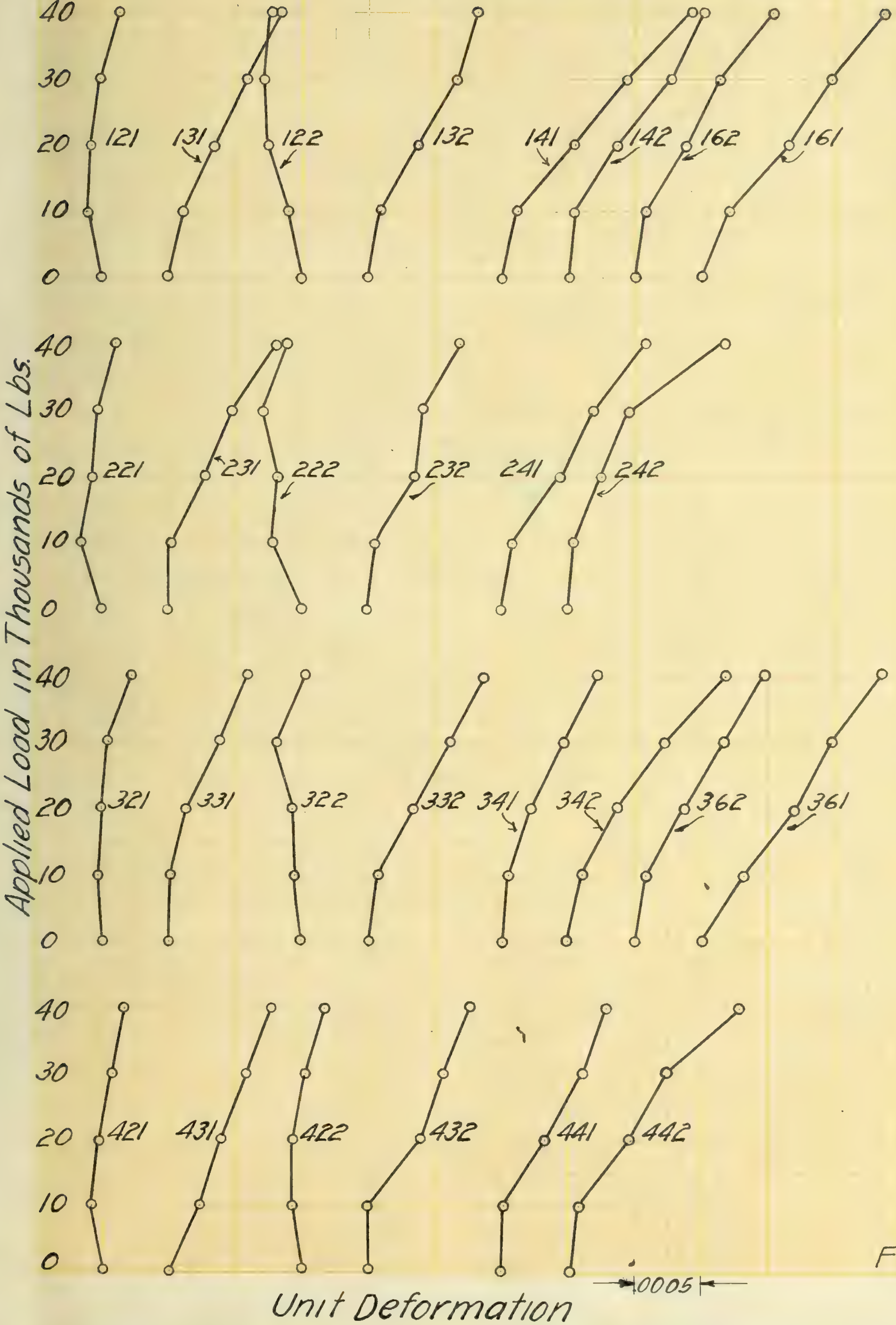


Fig. 19b.

16 B-16-1 4·17·17

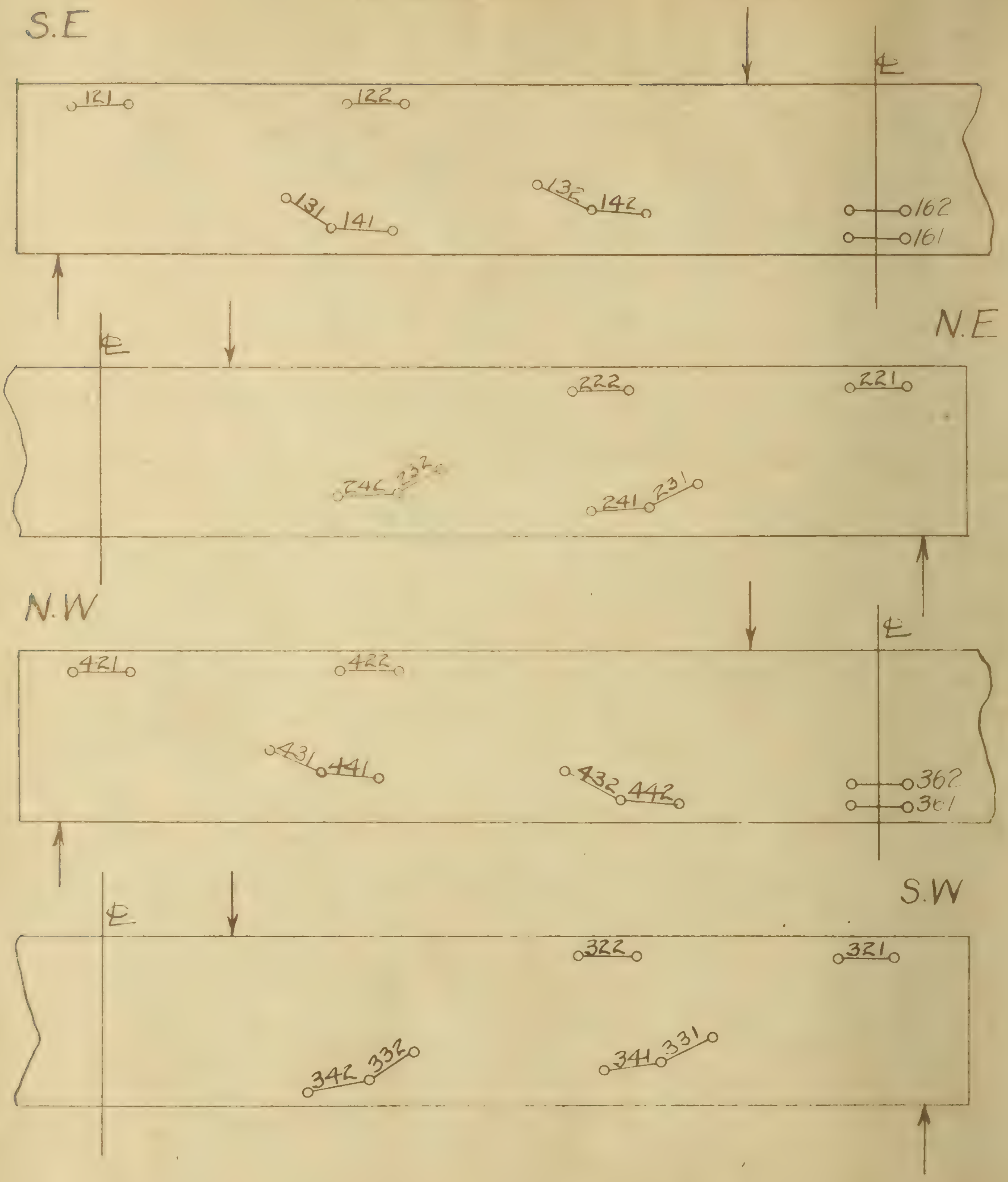


Fig. 20a

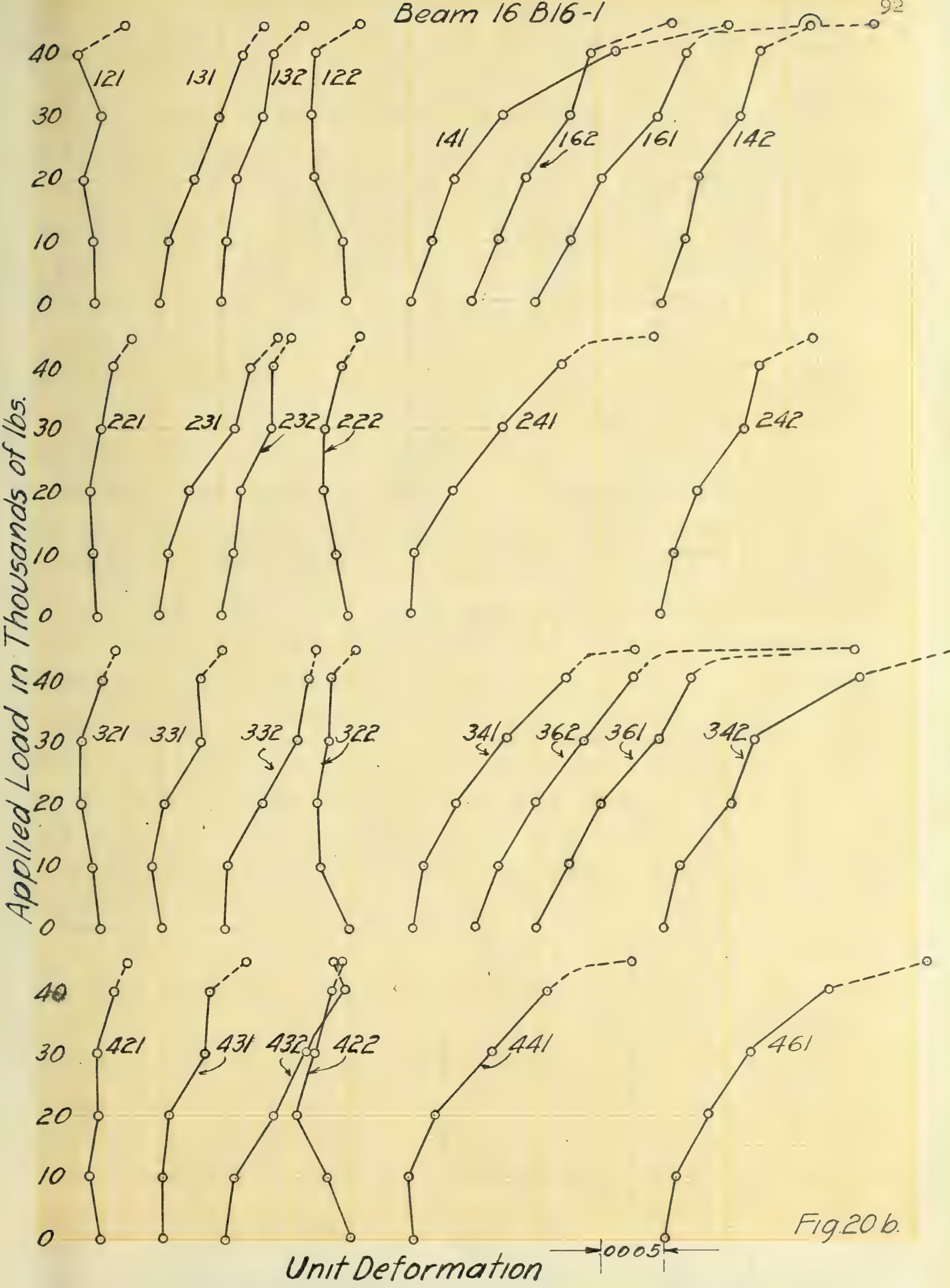

Beam 16 B16-1
Applied Load in Thousands of lbs.
0
10
20
30
40
121
131
132
122
141
162
161
142
221
231
232
222
241
242
321
331
332
322
341
362
361
342
421
431
432
422
441
461
Unit Deformation
.0005

Fig. 20 b.

[illegible] in concentration on each period.

16 B17-1 4-14-17

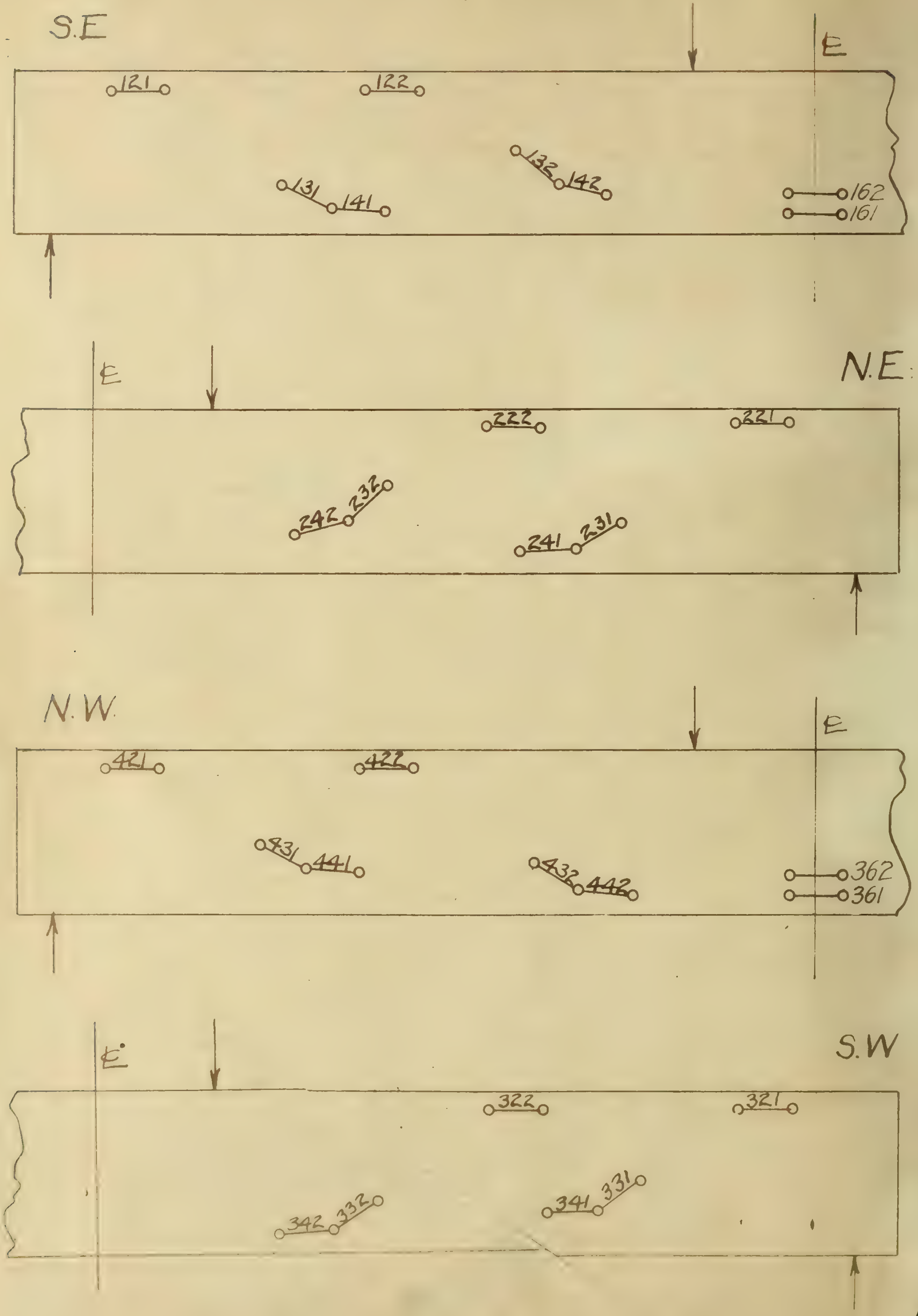


Fig. 21a.

Beam 16 B17-1

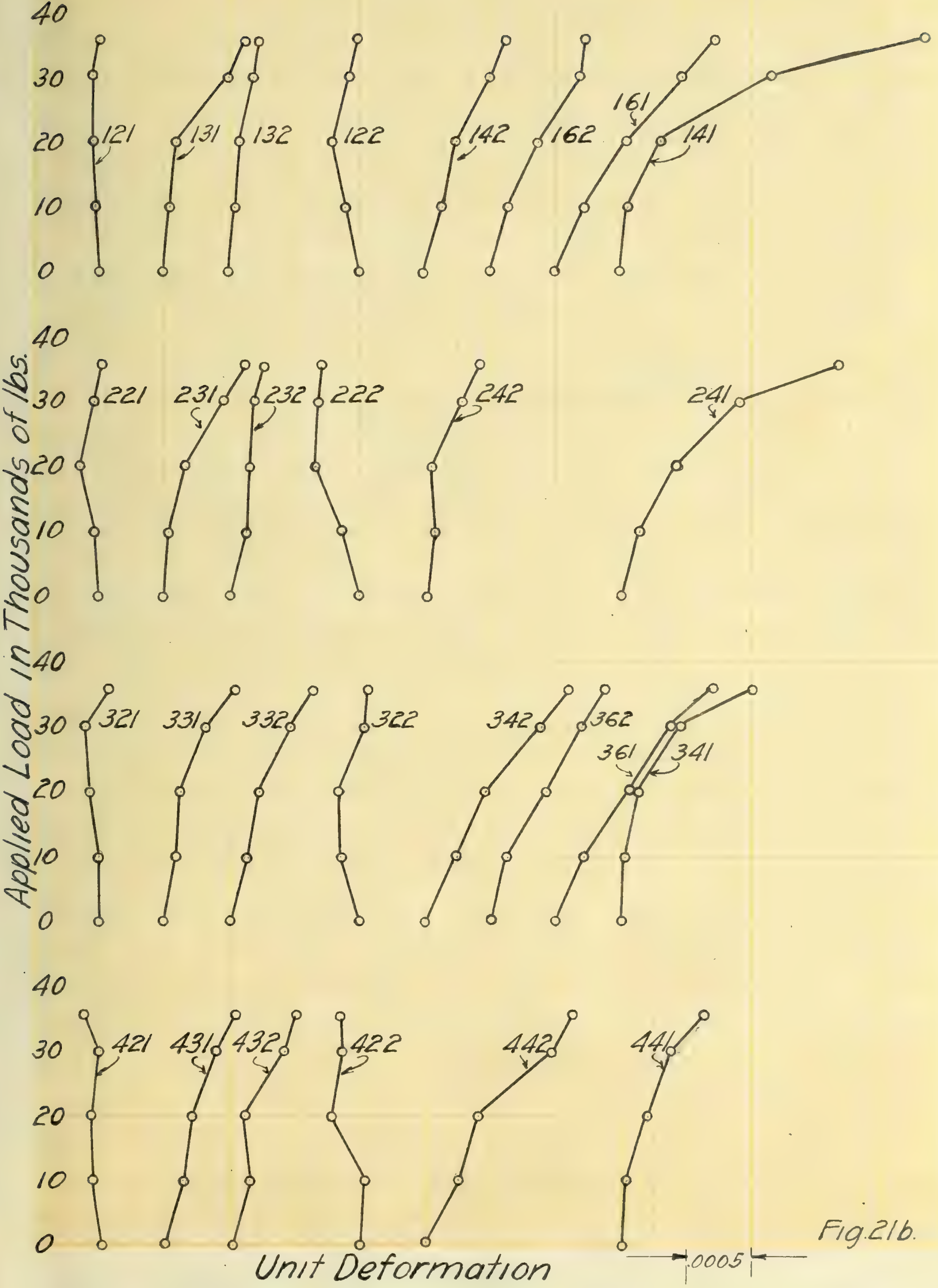


Fig. 21b.

16 B-18-1 4-18-17

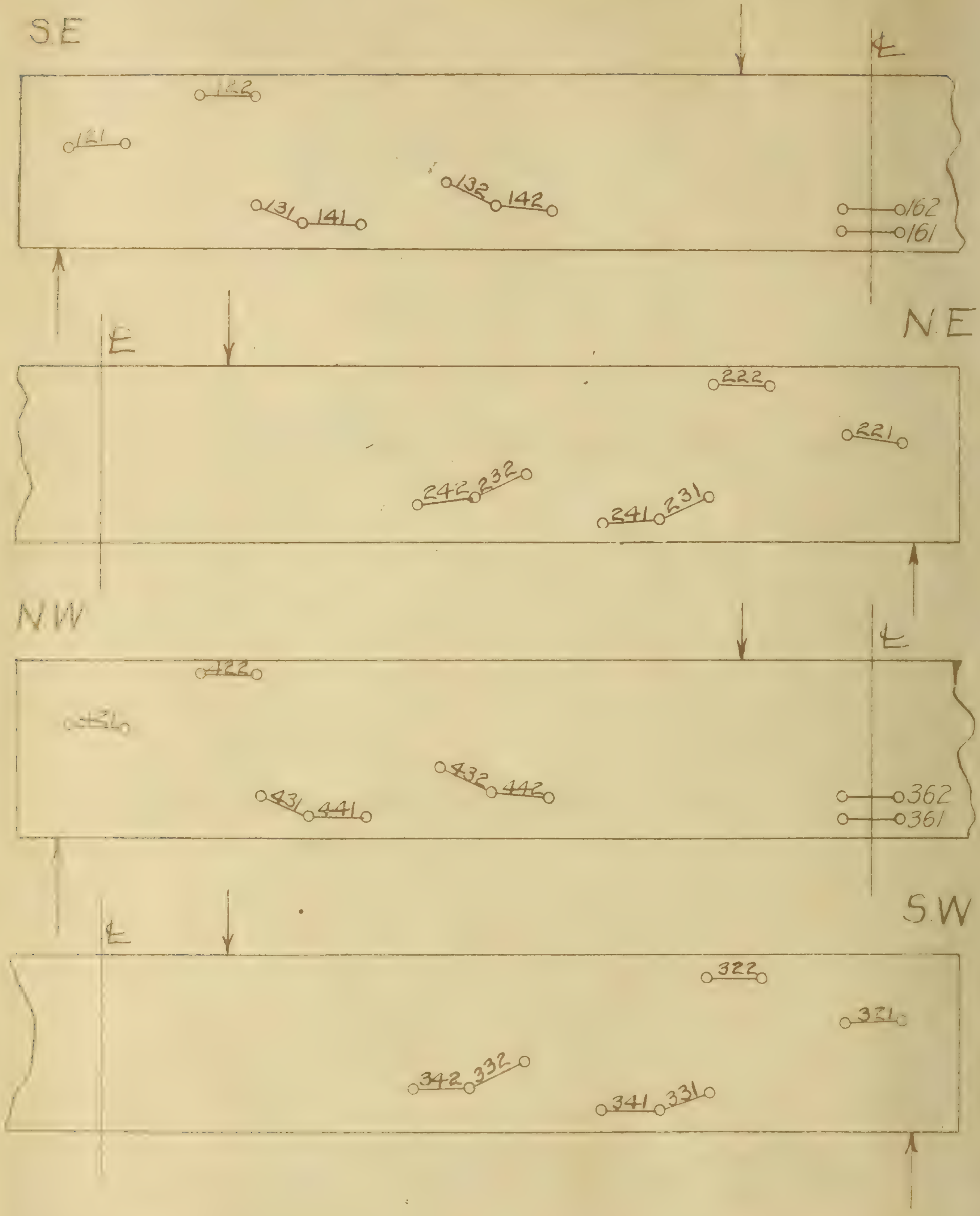


Fig. 22a.

Beam 16 B18-1

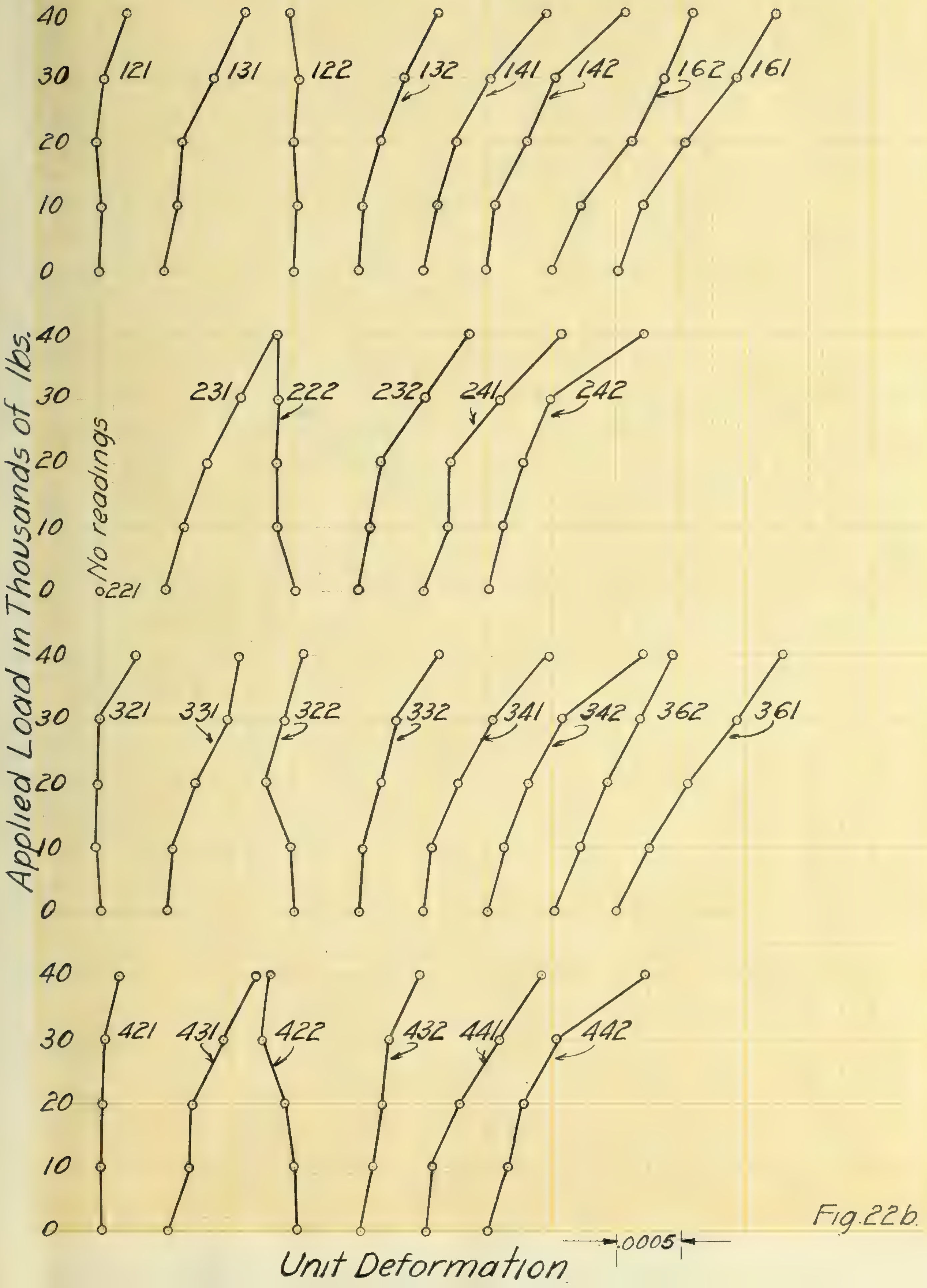


Fig. 22b.

16 B19-1 4-18-17

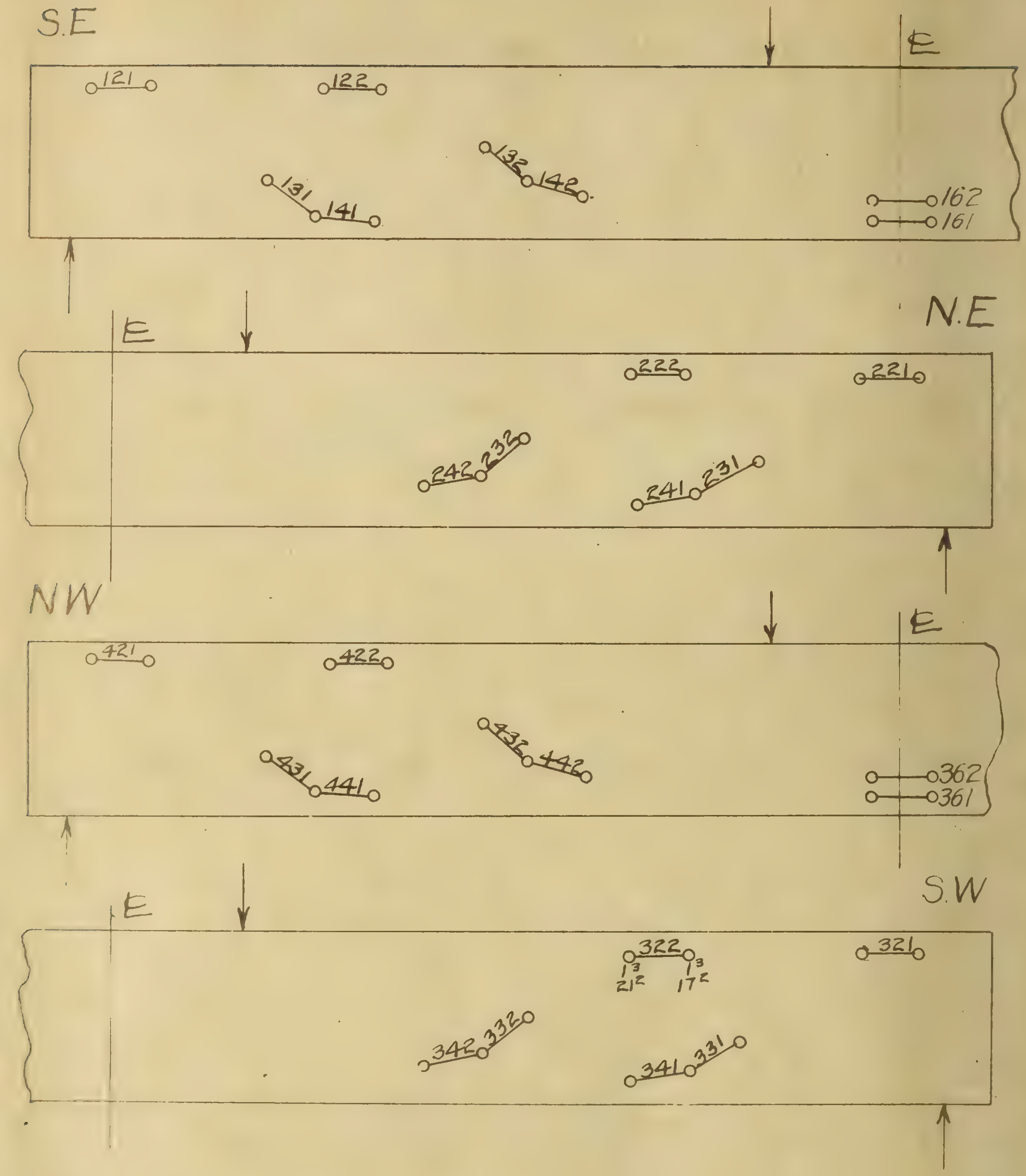


Fig.23a

Beam 16 B19-1

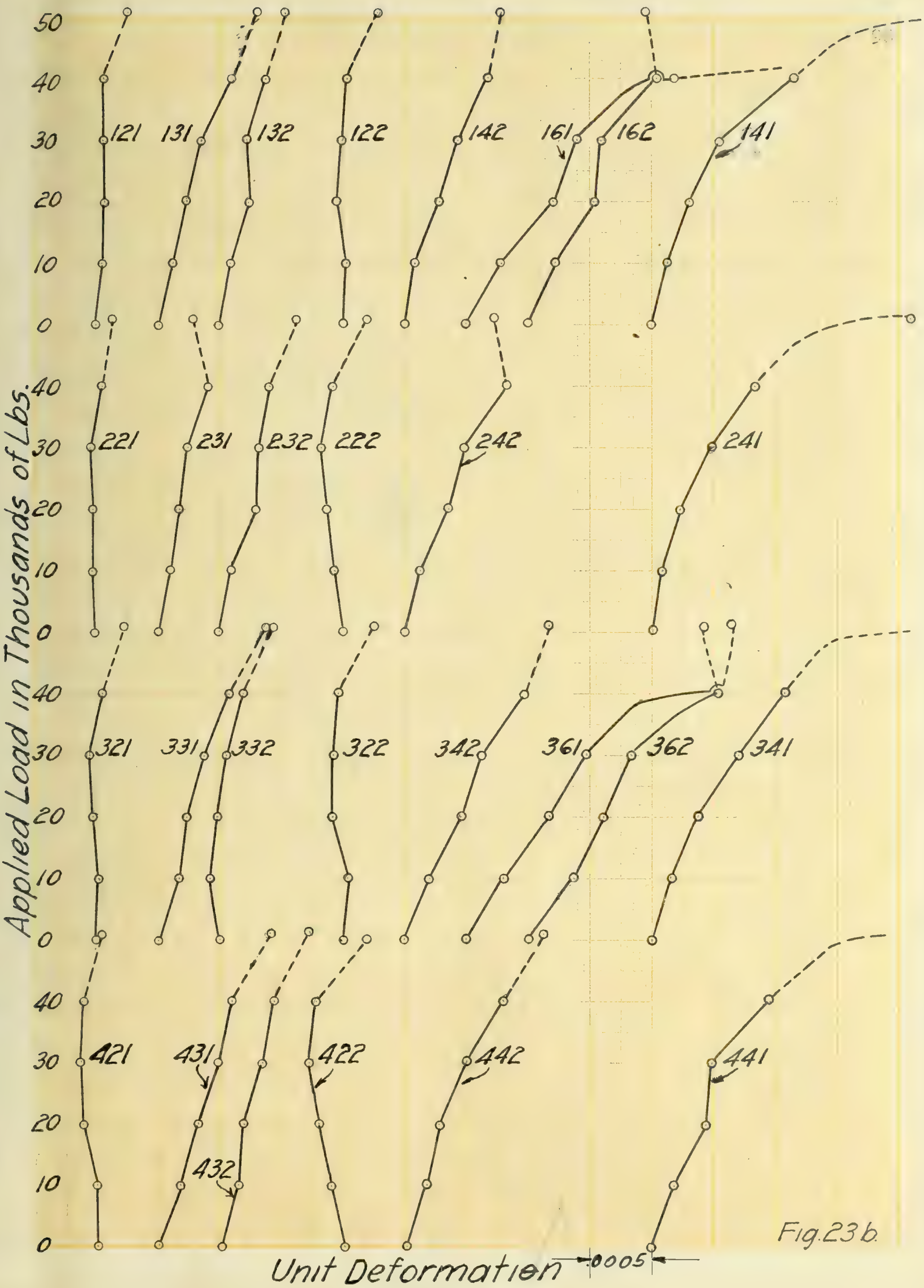


Fig. 23 b.

16B19-2

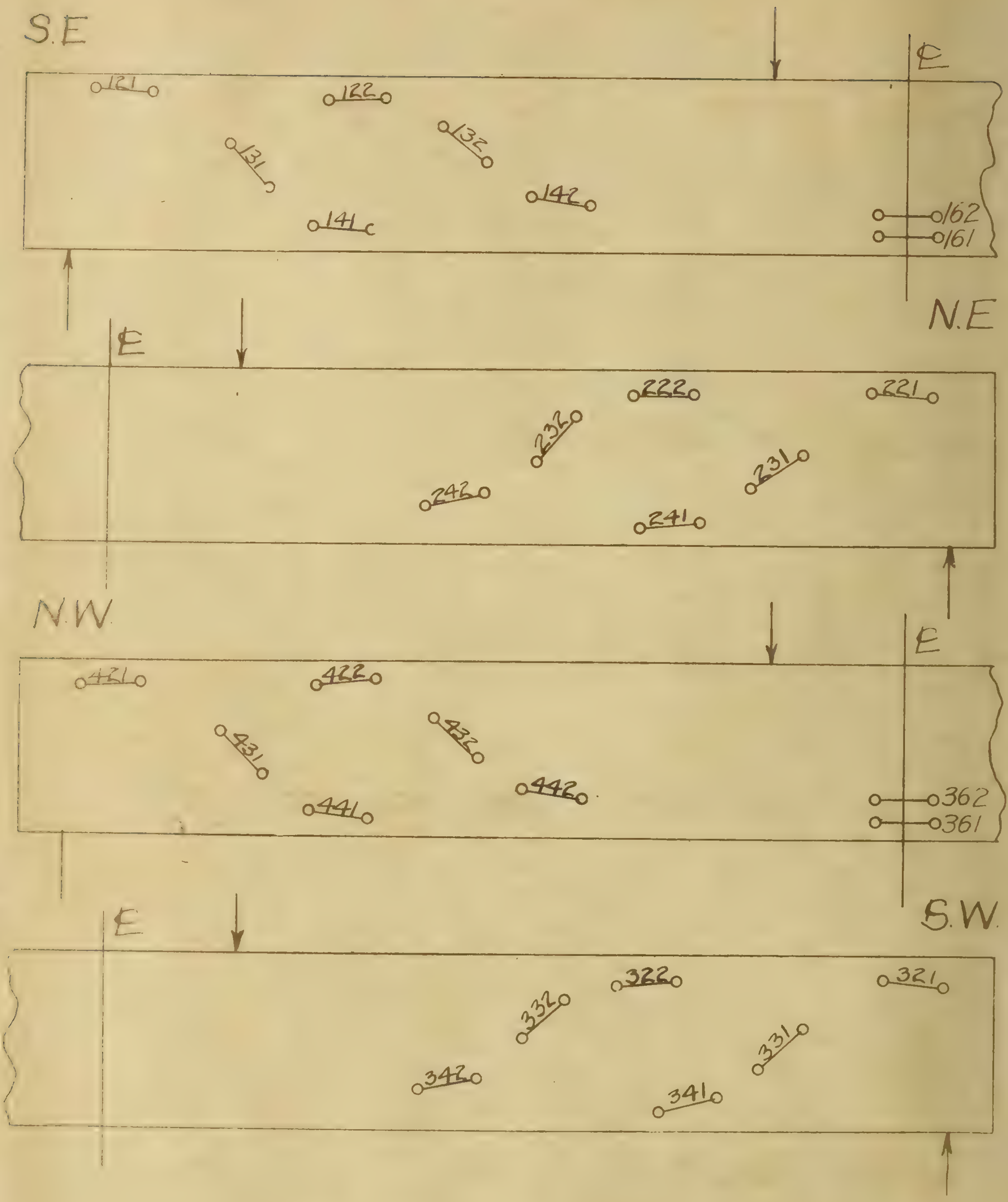


Fig.24a.

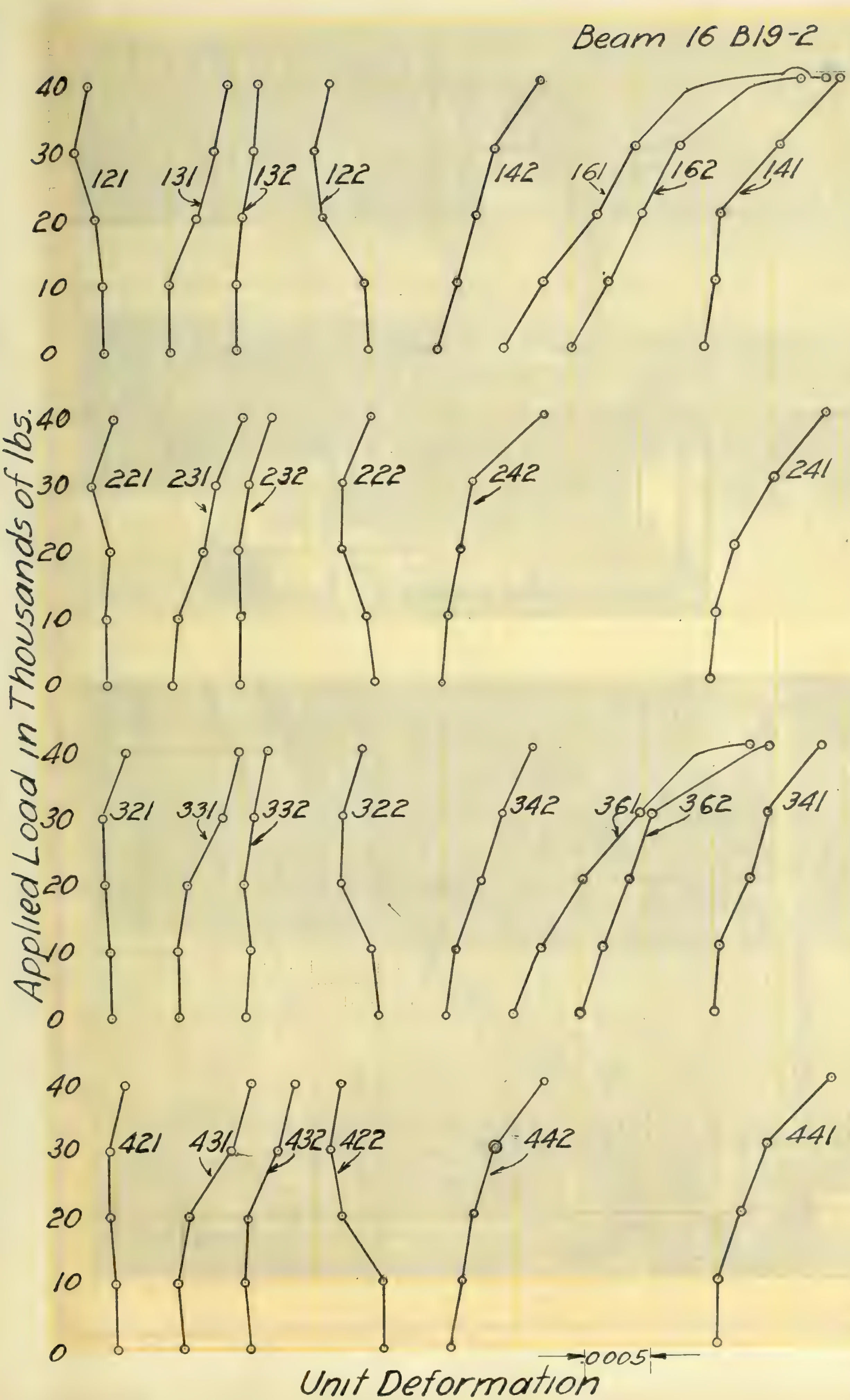

Beam 16 B19-2
Applied Load in Thousands of lbs.
40
30
20
10
0
121
131
132
122
142
161
162
141
221
231
232
222
242
241
321
331
332
322
342
361
362
341
421
431
432
422
442
441
.0005
Unit Deformation

Fig. 24b

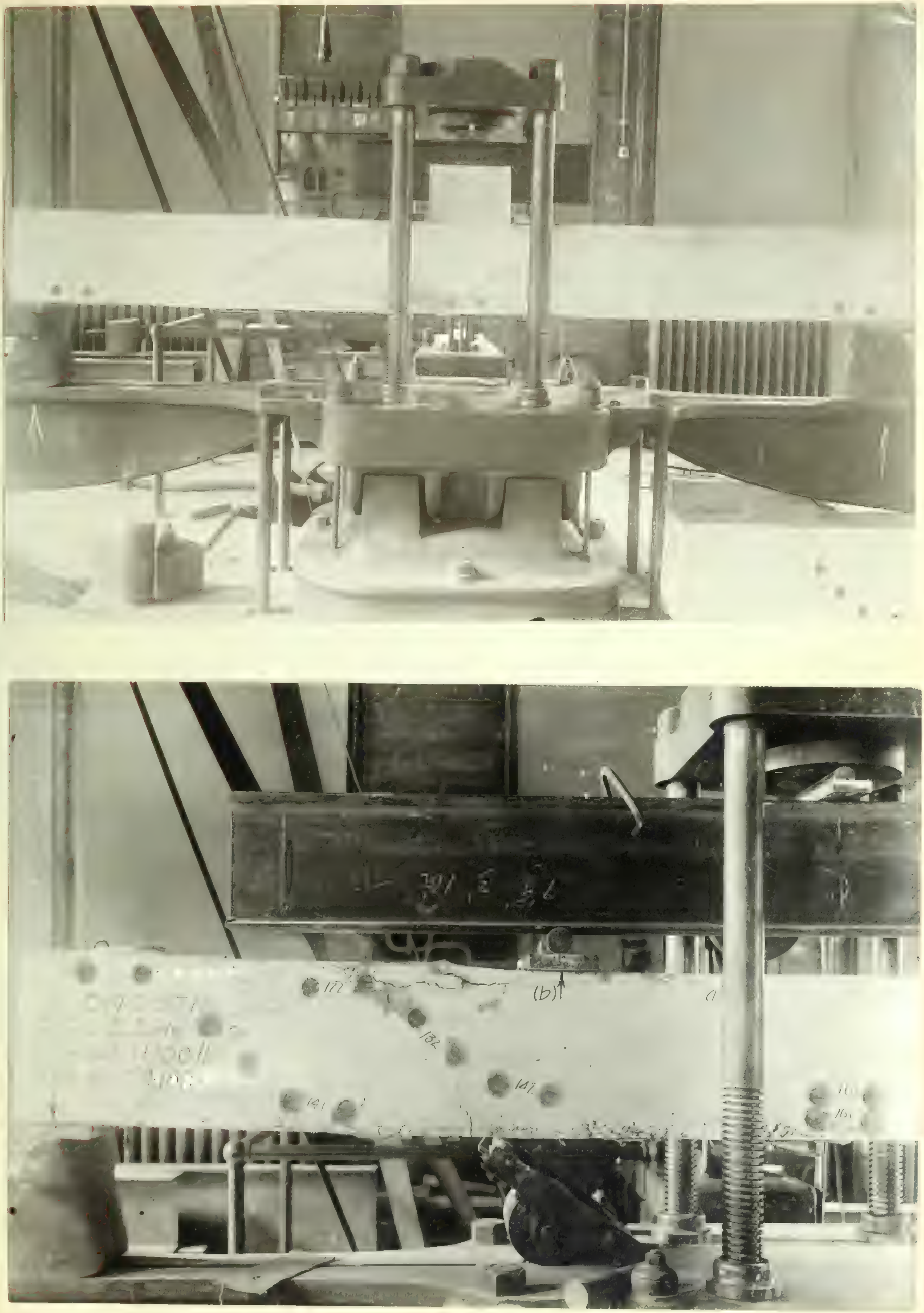
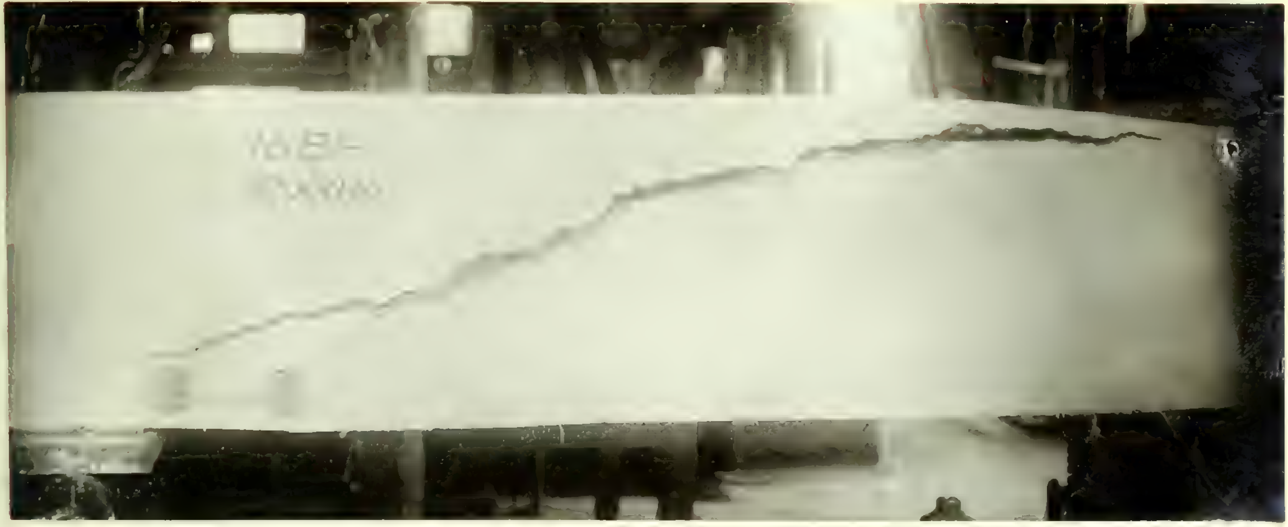
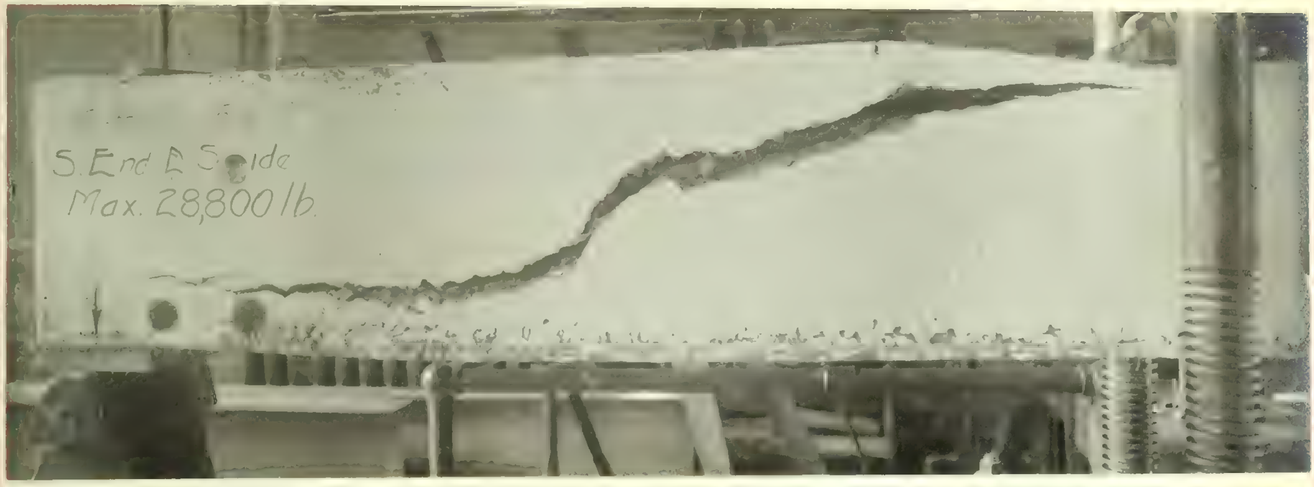


Fig. 25





B 2 – 1

Fig.26

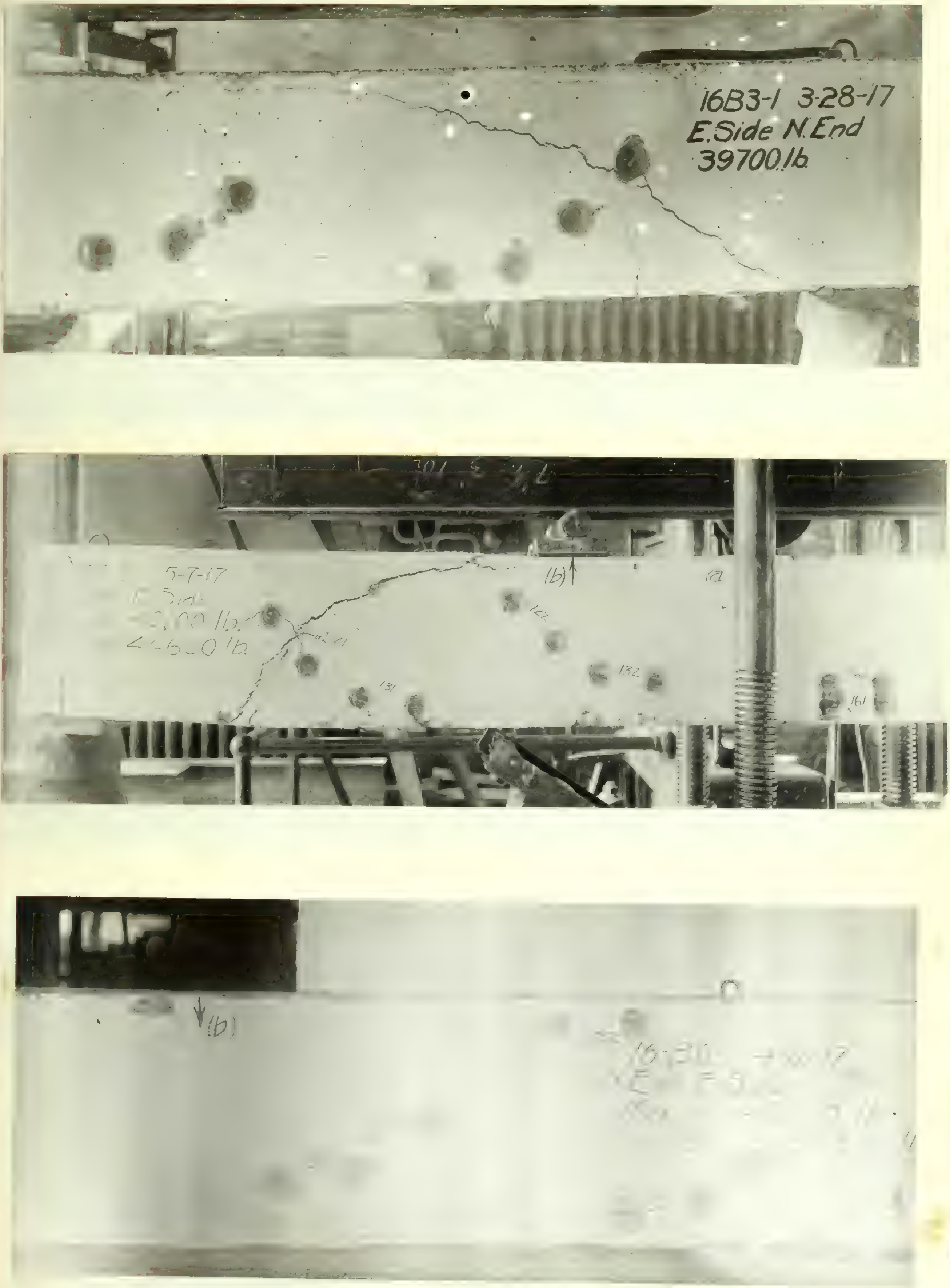


Fig. 27

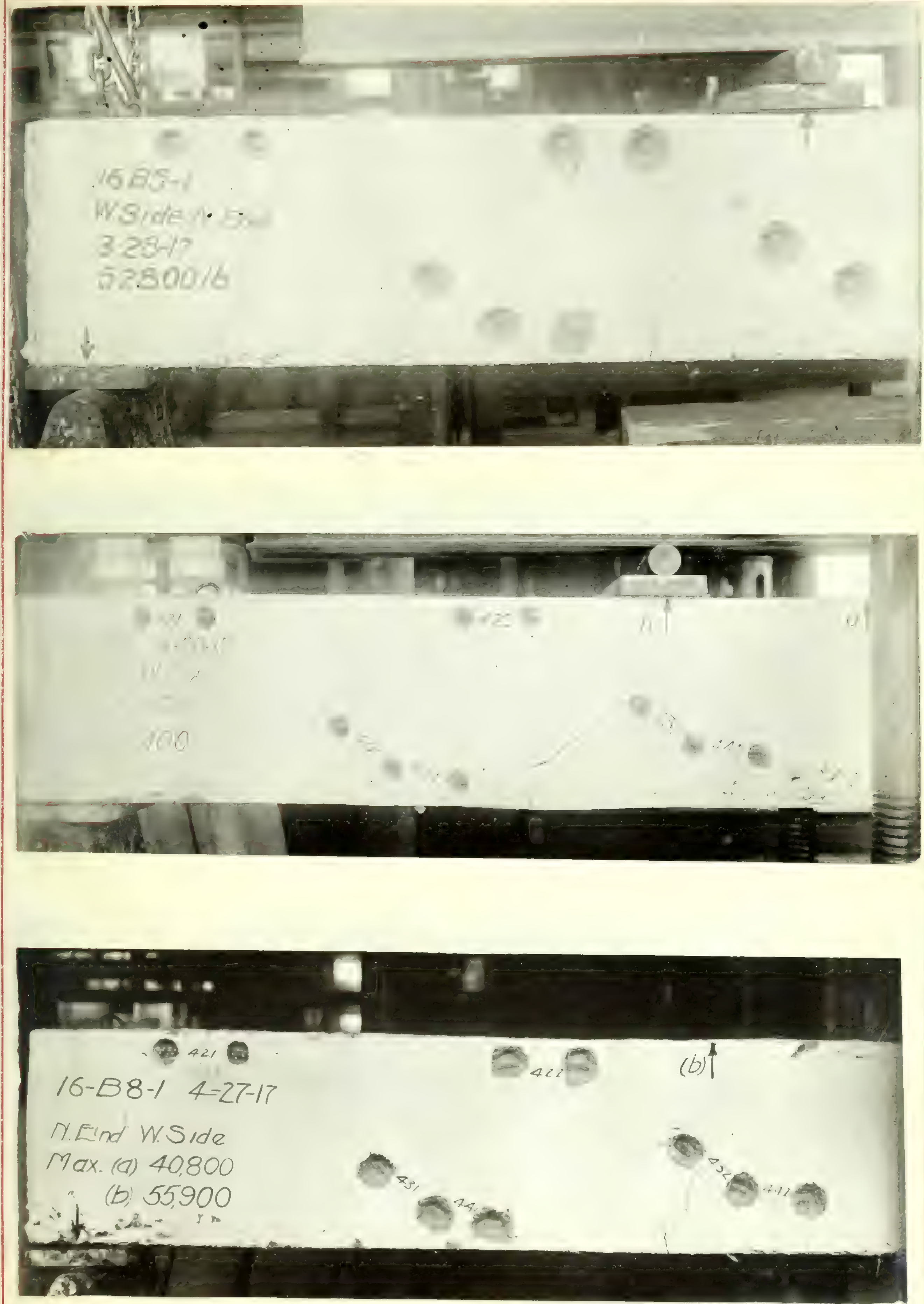
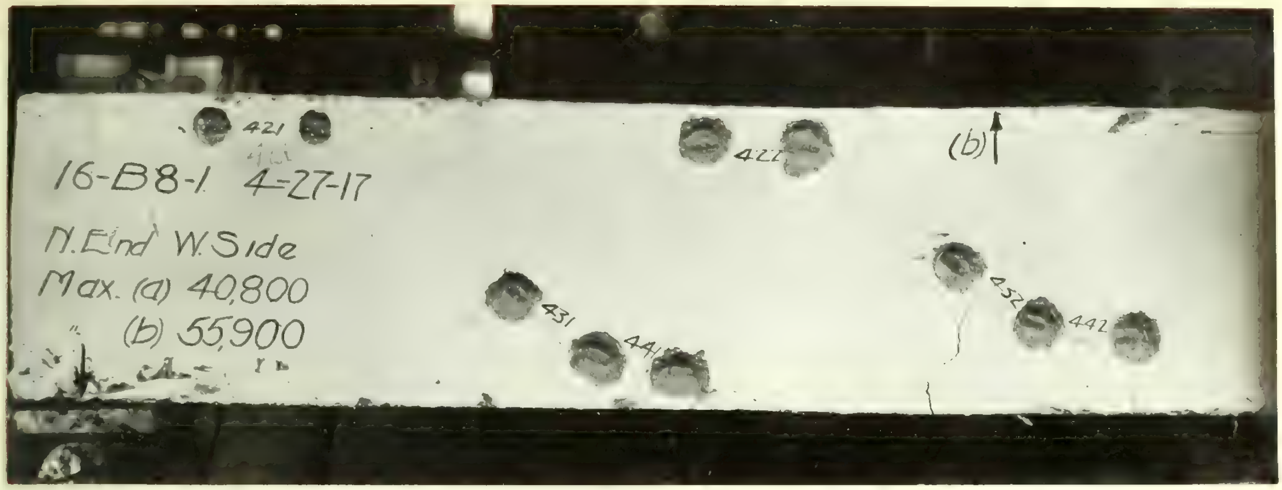
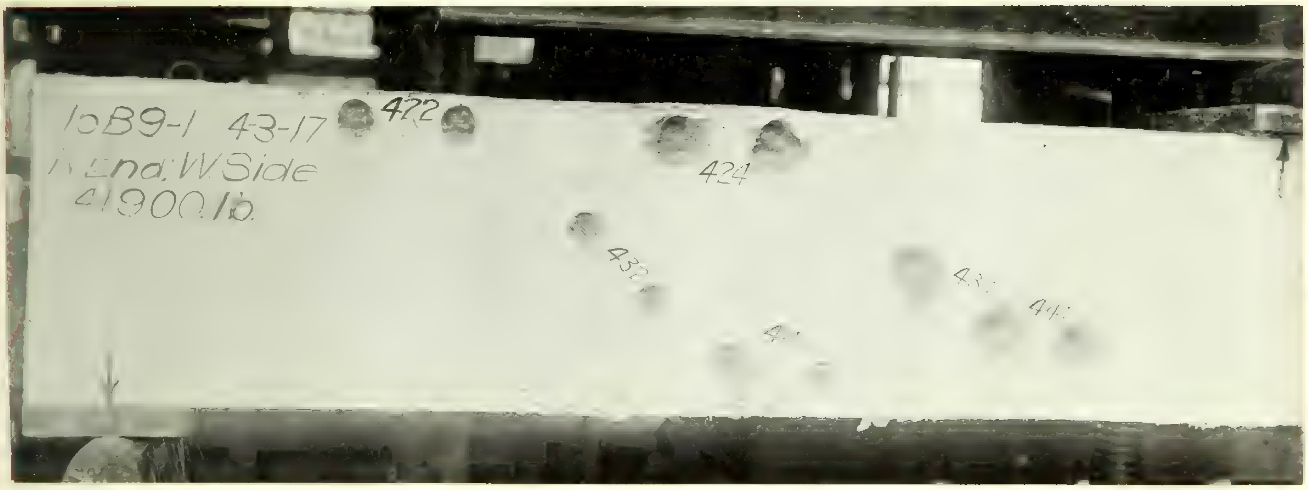

16 B5-1
W. Side N. End
3-28-17
52,800 lb
422
400
(a)
421
421
422
(b)
16-B8-1 4-27-17
N. End W. Side
Max. (a) 40,800
" (b) 55,900
431
441
432
442

Fig. 28


16-B8-1 4-27-17
N. End W. Side
Max. (a) 40,800
(b) 55,900
421
422
(b)
431
441
432
442


16B9-1 4-3-17
N. End W. Side
41900 lb.
422
424
431
432
441
442

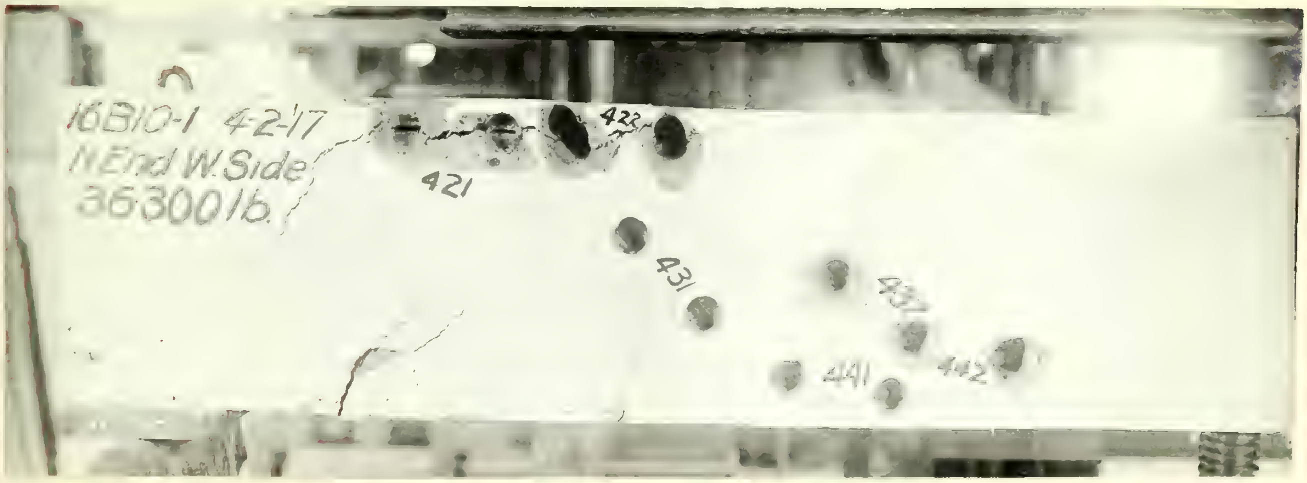

16B10-1 4-2-17
N. End W. Side
36300 lb.
421
422
431
432
441
442

Fig. 29

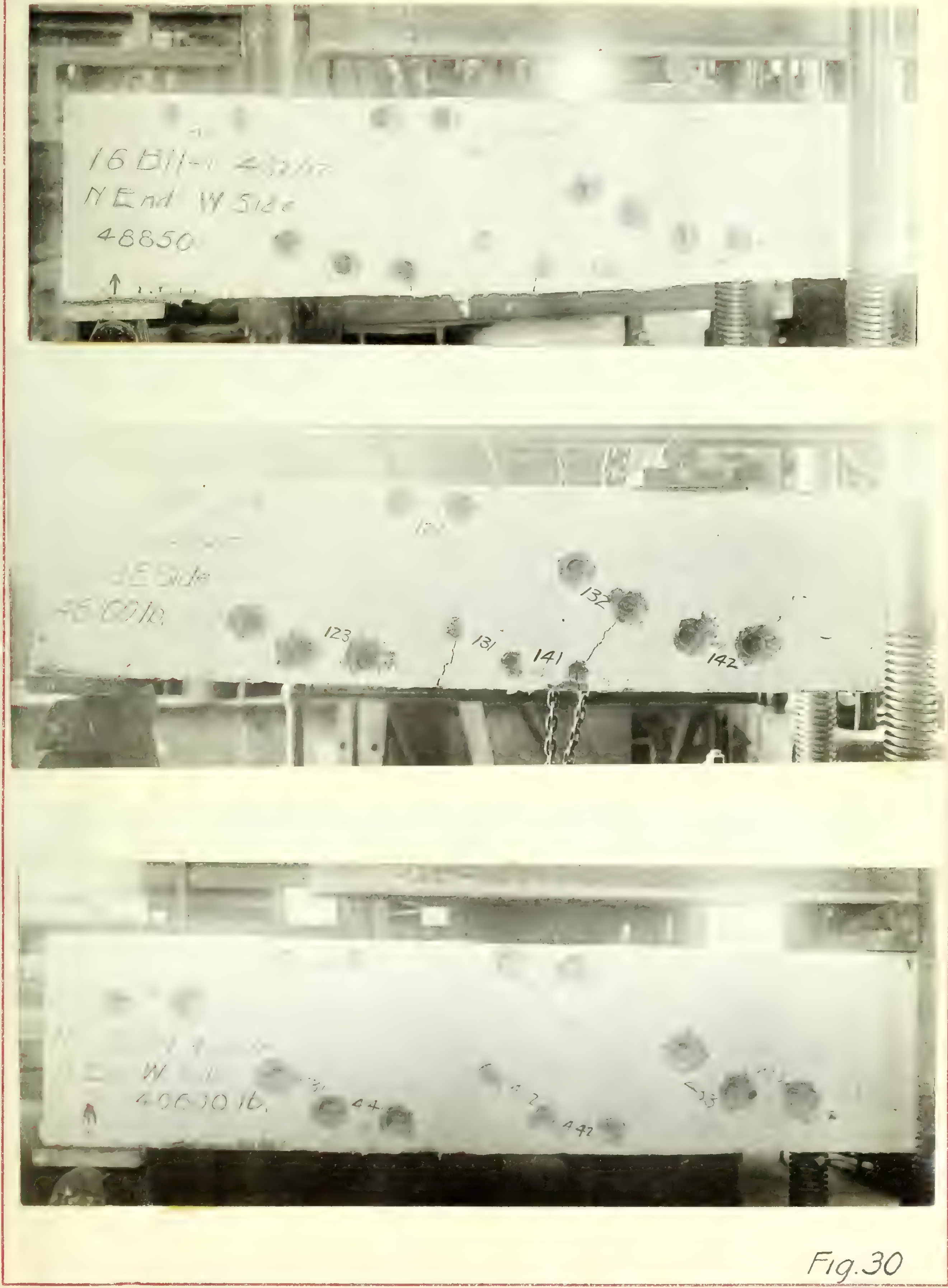

16 BII-1 4
N End W Side
48850
E Side
46100 lb.
123
131
141
132
142
W
40600 lb.
44
442

Fig.30

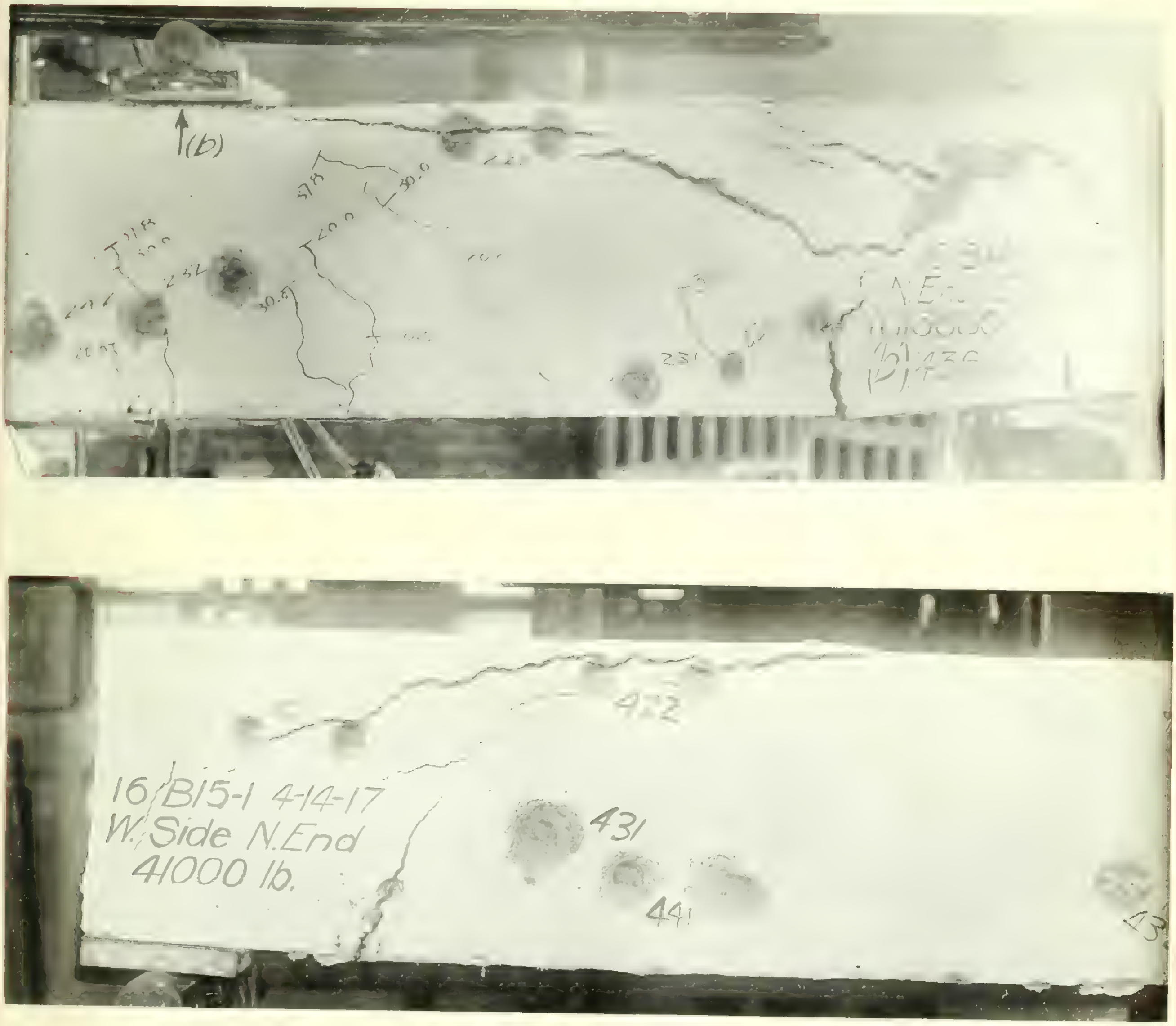
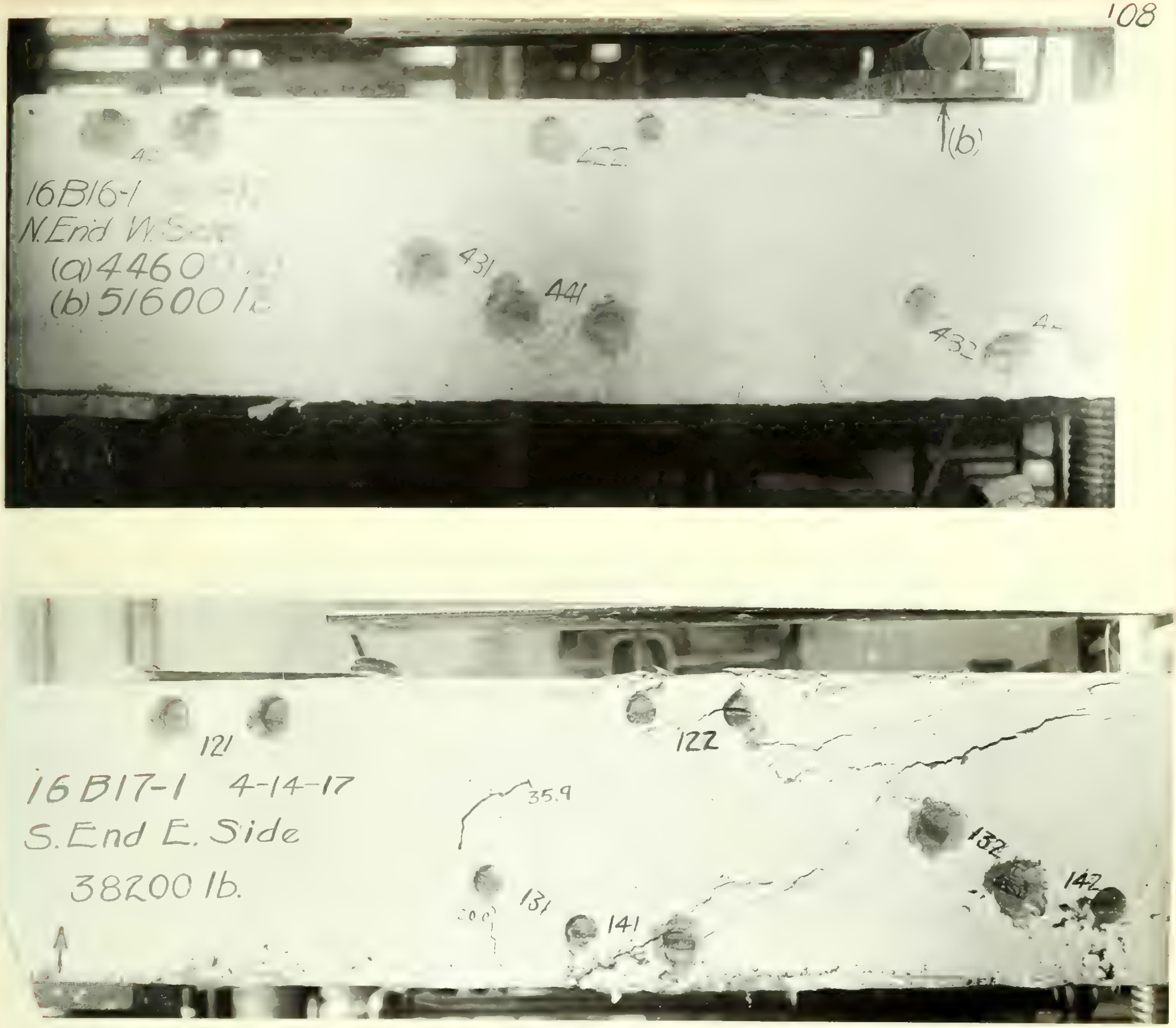


Fig. 31



(b)
422
16B16-1
N.End W.Side
(a)4460
(b)51600
431
441
432
121
122
16B17-1 4-14-17
S.End E.Side
38200 lb.
35.9
131
141
132
142

Fig. 32

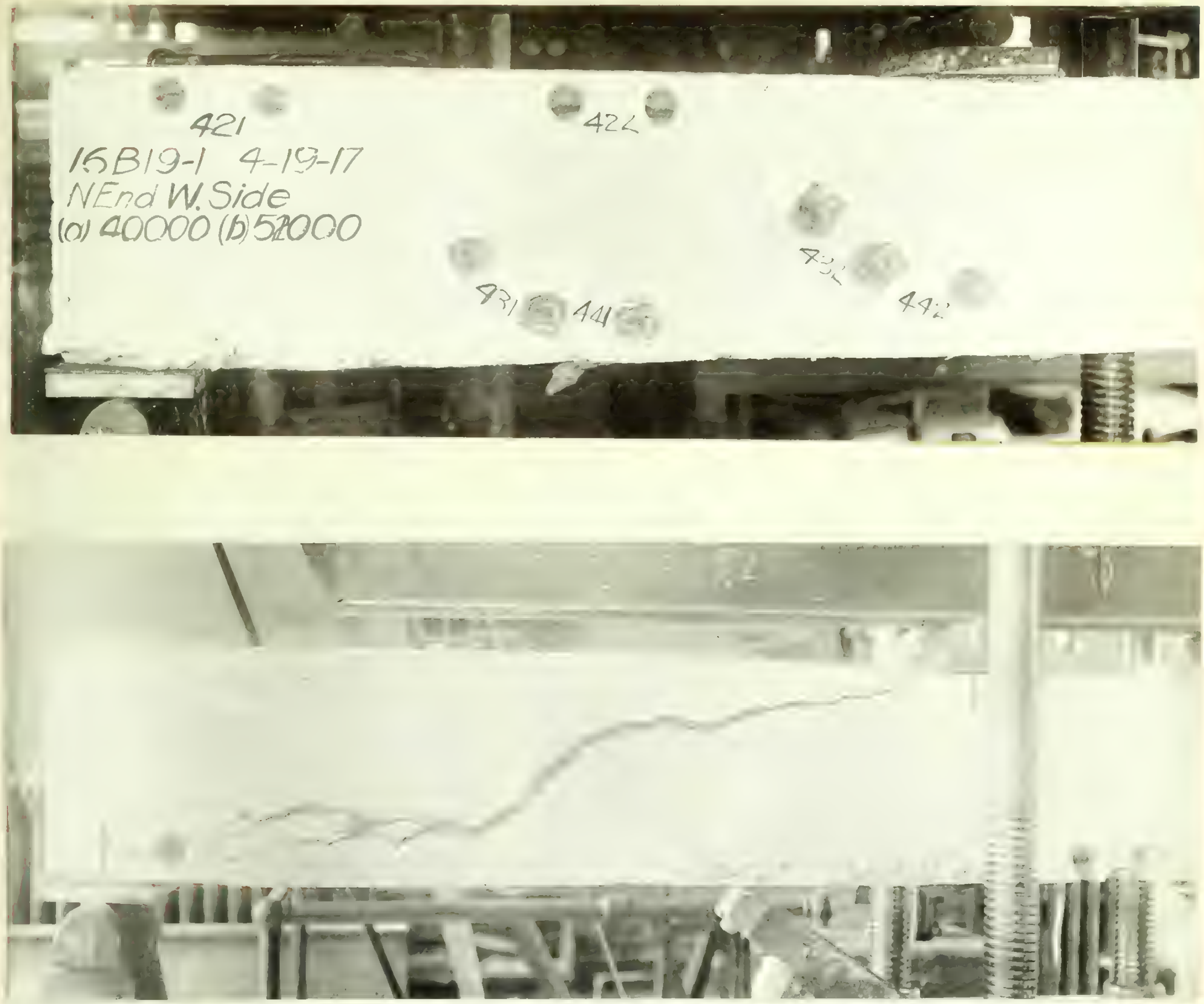

421
422
16B19-1 4-19-17
N End W. Side
(a) 40000 (b) 52000
431
441
432
442
16-B21-2
N.End W. Side

Fig. 33

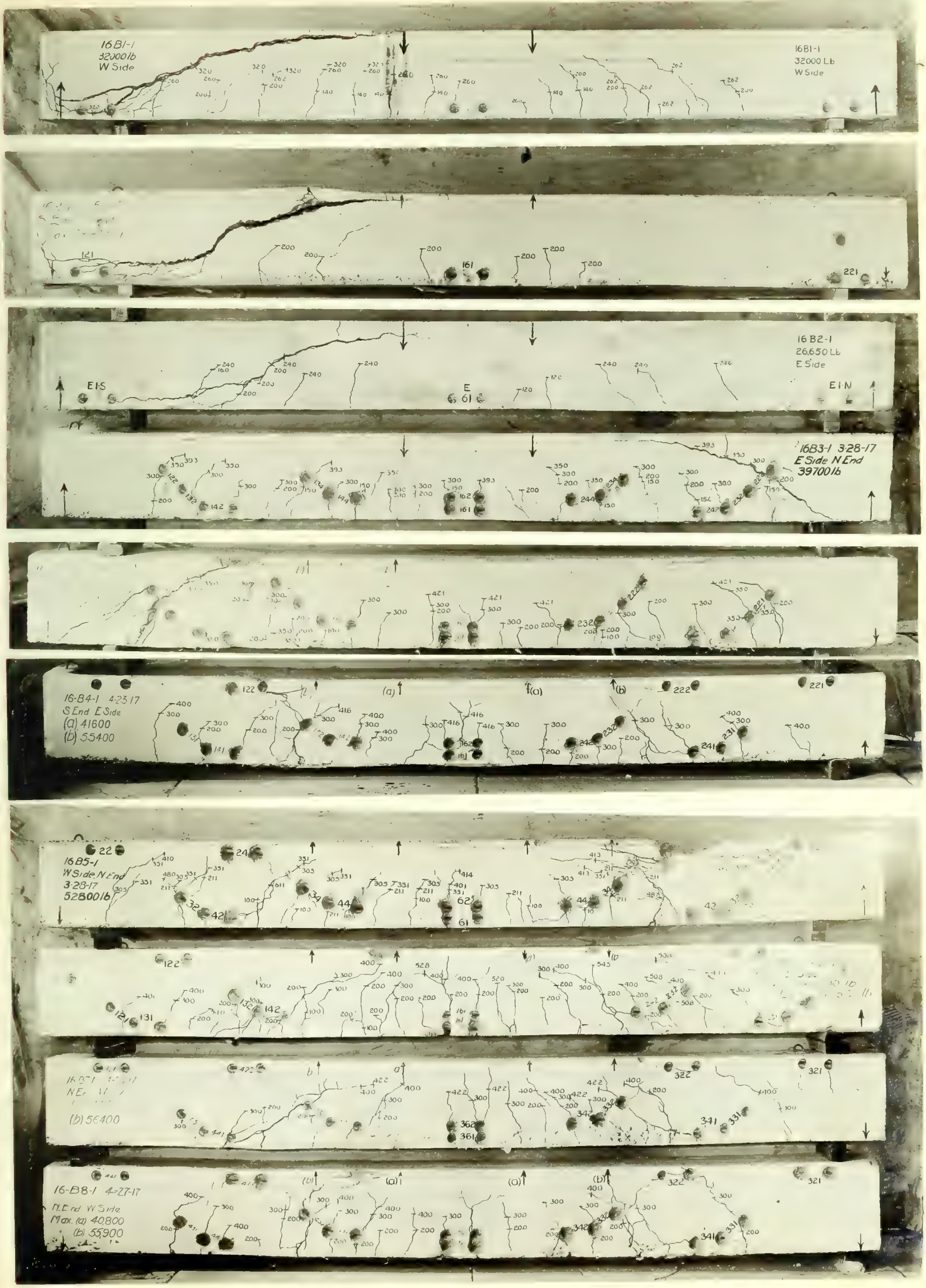

16B1-1
32000 lb
W Side
16B1-1
32000 Lb
W Side
16B2-1
26,650 Lb
E Side
E1-S
E
61
E1-N
16B3-1 3-28-17
E Side N End
39700 lb
16-B4-1 4-23-17
S End E Side
(a) 41600
(b) 55400
(a)
(b)
16B5-1
W Side N End
3-28-17
52800 lb
(b) 56400
16-B8-1 4-27-17
N End W Side
Max. (a) 40,800
(b) 55,900

Fig. 34

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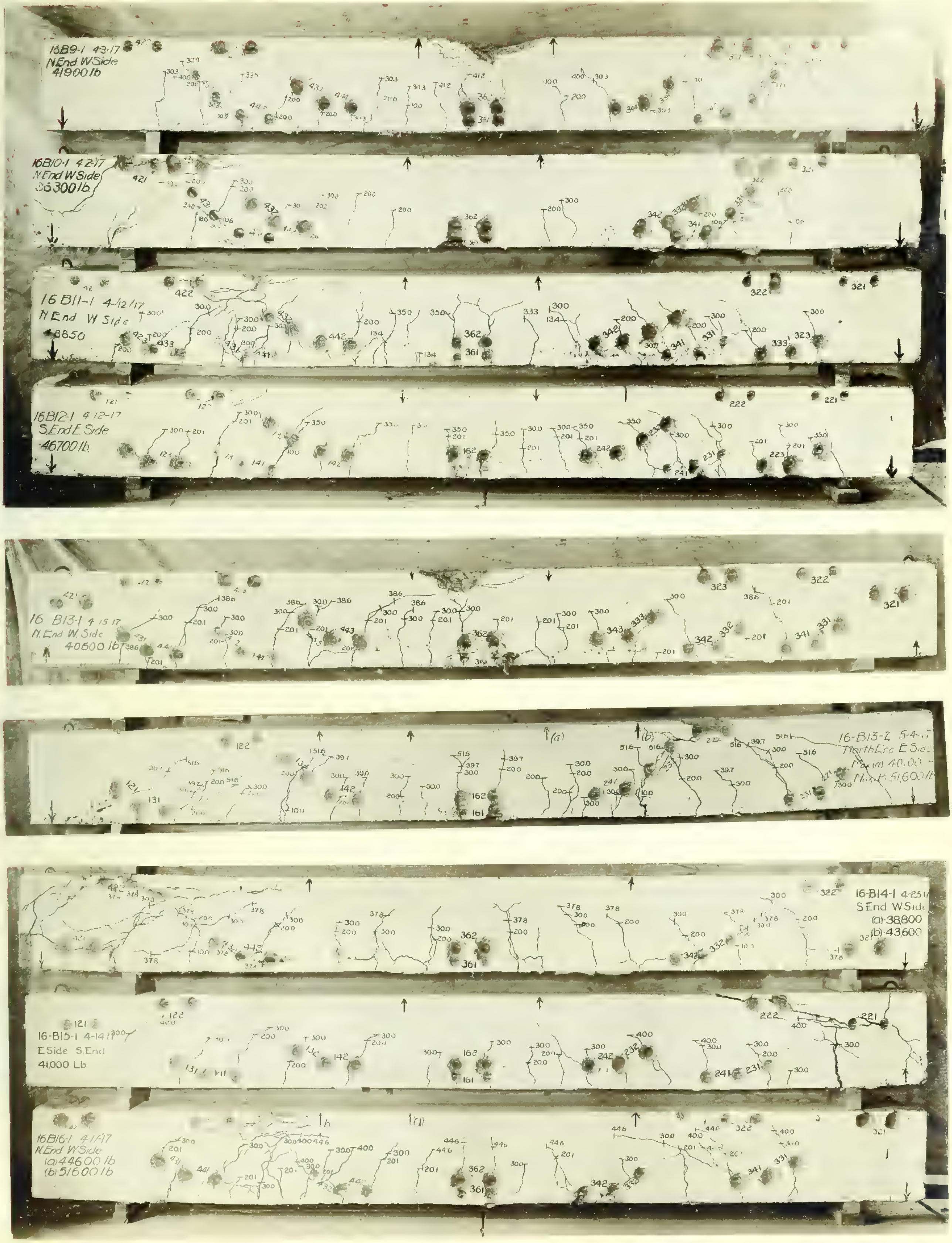
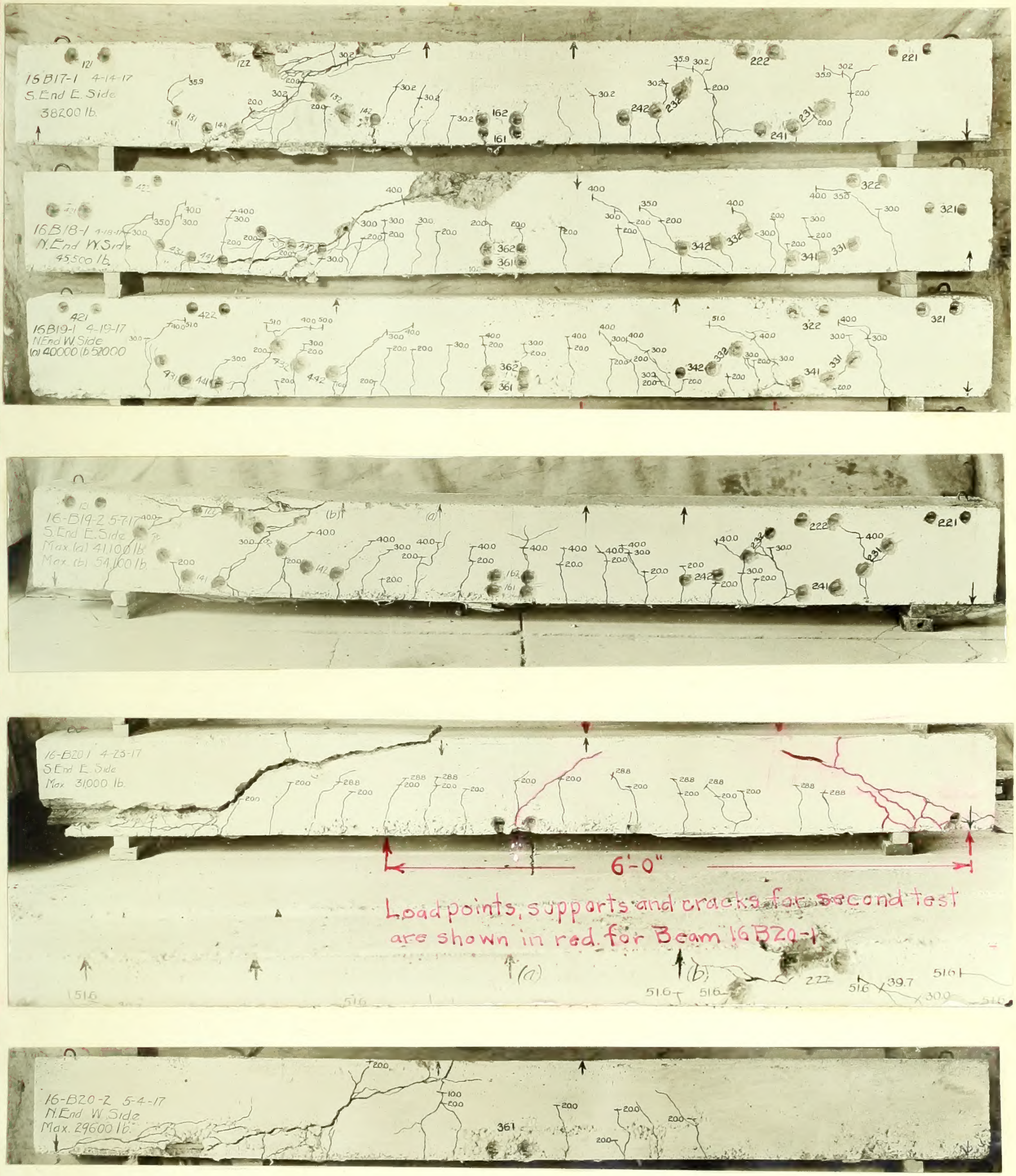

16B9-1 4-3-17
N.End W.Side
41900 lb
16B10-1 4-2-17
N.End W.Side
36300 lb
16 B11-1 4-12-17
N End W Side
48850
16B12-1 4-12-17
S.End E.Side
46700 lb.
16 B13-1 4-15-17
N.End W.Side
40600 lb
16-B13-2 5-4-17
North End E Side
Max (a) 40,00
Max (b) 51,600 lb
16-B14-1 4-25-17
S End W Side
(a) 38,800
(b) 43,600
16-B15-1 4-14-17
E Side S.End
41,000 Lb
16B16-1 4-17-17
N.End W.Side
(a) 44600 lb
(b) 51600 lb

Fig. 35



Load points, supports and cracks for second test are shown in red for Beam 16B20-1

Fig. 36

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